# THE HYDROGEOLOGY OF THE CHEVIOT REGION, NORTH CANTERBURY, NEW ZEALAND.

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A Thesis
Submitted in Partial Fulfilment
of the Requirements for the Degree
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THESIS with 3 maps in back pocket

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## ABSTRACT

In 1967 a pump station was installed on a bore in the north west portion of the Spotswood Plains, and although it has provided an adequate supply to the farms and main township of the region, Cheviot, the water supply has on a number of occasions failed to meet demand. Consequently this study was initiated to examine the geology of aquifer systems, to quantify by hydrological gaugings and pump tests the groundwater system of Spotswood and to determine the groundwater resources of the other major plains area of Mina.

The Spotswood Plains cover 28.5 $km^2$ and are transgressed by the Waiau River and Leamington Stream which for the 1986-87 period had mean yearly flows of 98676 and 456 $ls^{-1}$ respectively. The Mina Plains cover only 16.0 $km^2$ and contain three streams, Mina, Swamp and Crystal Brook which do not maintain surface flow from November to March and whose flow rates in the other months range in 1986-87 from 8 to 196 $ls^{-1}$. The average number of days where rainfall was recorded for each month during the period November to January 1987 was only five, illustrating the dependence of the areas aquifers on recharge from surface streams.

Geological investigations have shown that the aquifer in Spotswood consist of at least four stratigraphic units which in general terms, represent successive aggradational and degradational periods during cyclic climatic variations throughout the Quaternary Period. Geophysical investigations have targeted all of these units apart from the oldest unit, SO in Spotswood and MO in Mina which are not water bearing. Electrical resistivity soundings showed that the aquifer in Spotswood ranges from 10 to 80 metres, on average 40 metres thick, and consists of unconsolidated gravel within a sandy matrix (average resistivity of unit, 422 ohm-m), underlain by a relatively impermeable silty mudstone (average resistivity of 30 ohm-m). The lithologically equivalent unit in Mina was shown to be approximately 10 metres thick ranging from 7 to 16 metres, and consists of unconsolidated alluvium within a silty-clay matrix (average resistivity value of 140 ohms) again resting on silty mudstone, identified as Greta Formation by investigative drilling.

Borehole water level monitoring produced potentiometric surveys and flow nets which for the $14^{th}$ August 1987 showed that 47.23 $m^3/min$ was recharged to the aquifer system of Spotswood by the Waiau River and Leamington Stream (38.34 and 8.89 $m^3/min$ respectively) and that 28.81 $m^3/min$ was discharged back to the Waiau River through subsurface flow. Surface flow gaugings determined that for that same day in August 18.4 $m^3/min$ was discharged to the Waiau River. In the Mina Plains 0.815 $m^3/min$ was

recharged to the aquifer system, 0.047 $m^3$/min was discharged by subsurface flow and 2.00 $m^3$/min was estimated as discharging from surface streams and artesian bores.

Pumping tests showed that the alluvial material in Spotswood has a Transmissivity value averaging 5.2 $m^2$/min whilst the best transmissivity value obtained at Mina was 0.04 $m^2$/min. A step drawdown test determined that the suggested maximum drawdown in bore 19, an irrigation water supply bore would occur at 20 weeks based on a calculated long term pumping rate of 0.928 $m^3$/min.

A water quality survey showed that the groundwater in Mina is greater than 25 years old and contains concentrations of nitrate, chloride and sodium 2 to 4 times the desirable level set by New Zealand Health Standards. The contaminants originated as a consequence of agricultural practices such as the drilling of offal holes and the application of fertilizer. The groundwater of the Spotswood Plains was dated as less than 5 years old, and contained acceptable concentrations of contaminants primarily due to the dilution effect from recharge waters of Waiau River.

The groundwater system of the Mina Plains was proven to be an inadequate substitute to the water supply operation presently in operation in the Spotswood Plains. Further the Spotswood Plains aquifer system is under utilized and remains as an excellent source and potential source of quality groundwater.

# 1.0 INTRODUCTION

## 1.1 Background

A programme was initiated by the North Canterbury Catchment and Regional Water Board (N.C.C.B) to evaluate the water resources of the Cheviot region in January 1986. The investigation was to run for four years, with the ultimate aim of establishing management for the allocation of water rights which come up for review in 1990.

The investigation was also in response to an increase in demand from residents for quantitative information on the water resources in the region. Historically information has been limited to;

(1) Periodic records of water quality analysis on the groundwater located in the plains adjacent to the Waiau River and several analyses of the Waiau River water, in conjunction with the investigation for suitable locations for a county supply bore during the mid 1970's by the consultant engineers for the district (records held at N.C.C.B). Approximately five analyses have been recorded on the water of Cheviot pool taken during the late 1940's by Department of Health officials.

(2) Periodic flow gauging records from the Waiau River and Leamington Stream in the Spotswood area.

In September 1986, a masters project was formulated to compliment the pre-existing resource investigation of the N.C.C.B. The writer's contribution to the investigation was to assist in all aspects of the groundwater resource evaluation. This involved planning, setting up, carrying out, interpreting and analyzing all aspects of the common investigation techniques including: geological mapping, electrical resistivity, seismic refraction, stream gaugings, pump tests and nuclear borehole logging.

The primary objective of this study is to investigate the hydrogeology of the Cheviot region. The term hydrogeology as used throughout this thesis is defined as the science that deals with subsurface water and with related geological aspects of surface waters (Finkl 1984). The key objectives of the project were based on proven groundwater investigation outlines, such as those proposed in the United States' Bureau of Water Investigations manual (1985);

(i) appreciation of purpose.

(ii) scope of work required.

(iii) areal extent and geologic complexity of the area involved in the study.

(iv) limitations of time and finance, keeping in mind that the accuracy and reliability of acquired data usually increase with the time available for observation and interpretation.

## 1.2 Objectives

The following objectives were established;

A) Engineering geological and hydrogeological mapping of the Cheviot basin thus determining site development history and identifying geological controls present on groundwater movement.

B) Geophysical investigations, principally seismic refraction and resistivity surveys, supplementing geologic observations in defining aquifer distribution. Allowance was also made for downhole logging to be carried out on appropriate boreholes, once such boreholes had been located and/or drilled.

C) Aquifer yield characterization from pumping tests and groundwater recharge studies, which involved the setting up of a stream gauging and borehole monitoring programme with a view to determining the extent of ground water recharge.

D) Spring discharge monitoring to determine the nature and distribution of streams, natural springs and seepages over a range of lithologies and to gain quantitative data on flow rates over a one year cycle; September 1986 through to September 1987.

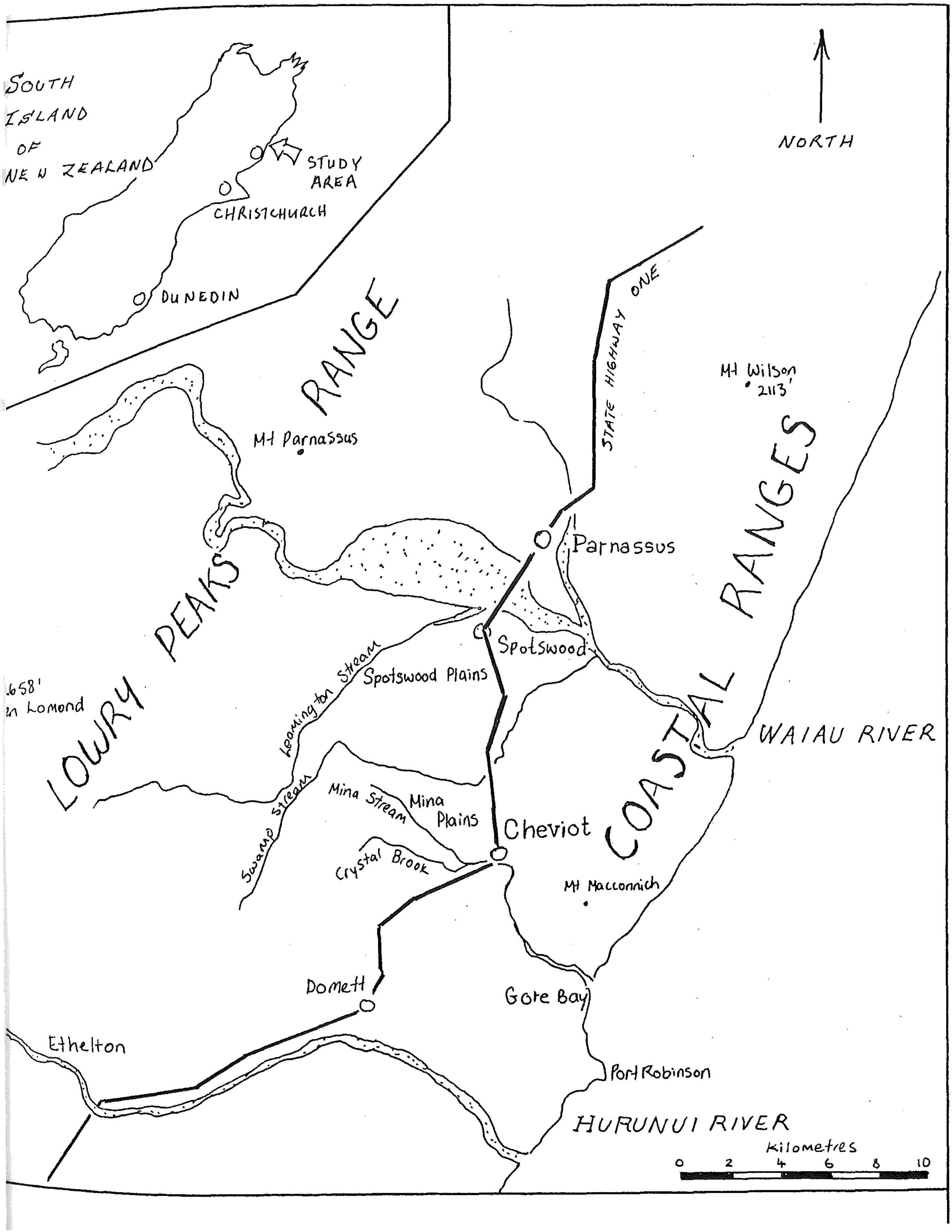
E) The assemblage and analysis of all hydrological monitoring and catchment studies, including the installation of an evaporation dish in the Cheviot township which provided the basis for a hydrogeological model for the basin.

## 1.3 Regional setting

### 1.3.1 Location

The north east trending Cheviot Basin region referred to in this study is located approximately forty metres to seventy metres above mean sea level approximately one hundred and fifteen kilometres north east of Christchurch city in Northern Canterbury (fig 1.1).

Fig 1.1 Location diagram of
study area, Cheviot region
North Canterbury


SOUTH ISLAND OF NEW ZEALAND
STUDY AREA
CHRISTCHURCH
DUNEDIN
NORTH
RANGE
LOWRY PEAKS
Mt Parnassus
STATE HIGHWAY ONE
Mt Wilson
2113'
COASTAL RANGES
Parnassus
Spotswood
Spotswood Plains
Leamington Stream
.658'
n Lomond
WAIAU RIVER
Swamp Stream
Mina Stream
Mina Plains
Cheviot
Crystal Brook
Mt Macconnich
Domett
Gore Bay
Ethelton
Port Robinson
HURUNUI RIVER
Kilometres
0 2 4 6 8 10

The region covers 198 $km^2$, is bounded to the north by the Waiau river and to the south by an uplifted belt of Pliocene marine sediments which isolate the Cheviot Basin from the main southern river of the region, the Hurunui river. The Western and Eastern margins are bounded by the Lowry Peak ranges and the coastal ranges respectively, (fig 1.1).

Within the greater limits of the region lie two smaller quite distinct plains areas of mostly flat terraced pastureland, namely Spotswood and Mina. The respective plains have been targeted as the main areas of interest as they constitute the greatest sources of groundwater in the region.

1.3.2 Geology

The geology of the Cheviot Basin can be divided into three dominant units (Fig 2.1);

(1) The Torlesse Supergroup: The Torlesse forms the basement for the region and outcrops extensively along the east and westerly bounding ranges. It comprises of greywackes argillites, conglomerates and occasional minor limestones and localized bodies of basic volcanics. Collectively this unit ranges in age from Triassic (approximately 235-190my BP) to the upper Jurassic / lower Cretaceous (older than 130my BP).

(2) Covering strata: The second unit unconformably overlies the first and is comprised of variety of lithologies, primarily marine siltstones, sandstones and conglomerate bands, which in places contain large blocks of Tertiary and older rocks. These rocks range in age from late Cretaceous (100my BP) to early - middle Pleistocene (c.a 1my BP).

(3) Quaternary deposits: The third and most recent unit comprises unconsolidated but compact fluviatile alluvium, generally very poorly sorted gravels and boulders within a matrix of fine silts and clays, overlain extensively by aeolian deposited loess. Successive periods involving substantial aggradation of gravel materials interrupted by periods of loess accumulation followed by subsequent degradation by streams and rivers have resulted in the occurrence of distinct remnant terrace surfaces throughout the region.

1.3.3 Tectonic development

The Cheviot basin lies within a belt of active folding and faulting involving both Torlesse basement and the Cretaceous - Pliocene covering strata. It's origin can be interpreted in terms of a hypothesis of antecedence, linked to five periods of climatic base level change. These periods are represented by stages of aggradation involving the formation of the Mina and Spotswood surfaces, lateral migration of rivers and streams and the development of the modern Waiau flood plain. Tilting of the oldest aggradational surface indicates active deformation along the Western and Eastern margins, associated with activity on the Kaiwara fault throughout the Quaternary period. Younger surfaces do not appear to have undergone deformation.

## 1.4 Regional hydrology

1.4.1 Climate

The Cheviot Basin traditionally receives 850 mm of rainfall annually (NZ Meteorological Statistics), ranging from 810 mm on the Spotswood plains to 880 mm along the eastern margin of the Lowry Peaks Range. During the year November 1986 to November 1987 the average rainfall was 662 mm, and the lowest period of rainfall occurred from November 1986 to January 1987 with an average of five rain days recorded in each month (Appendix 4.1).

Hot dry northwest winds predominate during autumn and summer causing seasonal soil moisture deficits, in July and August Easterly sea breezes are predominant. Throughout the year south westerly winds bring lower temperatures and rain. For the study period January 1987 to December 1987, temperatures ranged from 31.2$^{o}$c (1$^{st}$ January) to -3.0$^{o}$c (5$^{th}$ August). For the same period mean monthly temperatures ranged from 17.6$^{o}$c in January 1987 to 6.4$^{o}$c in July 1987, with a mean monthly temperature for the year of 11.8$^{o}$c (Appendix 4.1).

1.4.2 Surface hydrology

The Cheviot Basin is comprised of two main catchments here defined as northern and southern. The northern catchment contains the most dominant hydrological feature in the region, the Waiau River whose source can be traced to the footslopes of the Southern Alps near the Clarence fault approximately 55 km from the point at which it enters the Spotswood/ Parnassus plains' area through the incised gorge within the Lowry Peak ranges. The Waiau River significance as a source of recharge to the Spotswood Plains is evident considering that for the year November 1986 to November 1987 its mean daily flow was 98676 litres/sec (Table 4.2).

Leamington Stream is the only other significant stream in this catchment. For the period of this study it obtained a mean daily flow of 456 litres/sec (Table 4.2). The remainder of Spotswood Plains consist of a network of man made drains and surface seepage features which occur only after prolonged rainfall over several days, usually during the winter months.

One of the most noteworthy hydrological features in the Spotswood area is the existence of several permanent springs which occur adjacent to Waiau East road in Spotswood (fig 2.2). These springs occur in an area noted for its excellent groundwater supply and poor drainage and historically these sites have been used by residents of Cheviot township as a water supply source during periods of extended dryness.

The main hydrological features in the southern catchment are the Jed River, Swamp and Crystal Brook Streams and a previously unnamed little Mina tributary, Mina Stream (Fig 2.3). Swamp stream discharges from the central catchment zone, flows through to the Caroline stream and out to the Waiau River in the northern catchment. Each of the streams except Swamp Stream discharge into the Mina Plains but due to their intermittent flow only contribute to the aquifer system in the winter months of May through to September.

The southern quarter of the Mina plains area has a number of ground water seepages associated with a potentiometric water table occurring above ground surface. These seepages sustain limited seasonal flow in the winter months generally less than 0.5 l/s (Appendix 4.2). The streams and seepages of Mina plains area drain into the Jed River several hundred metres south of Cheviot township, and flow out to the coast in Gore Bay.

## 1.5 Investigative methodology

The work programme established for the Cheviot study followed six steps:

A) The collection and assessment of local information for the Cheviot region from town residents, historic information held in local museums and from local farmers;

B) Preliminary hydrogeological and geological mapping within the Cheviot basin in part to determine appropriate scales.

C) The establishment of a hydrological monitoring programme, incorporating surface and subsurface hydrology;

D) Before the initiation of a comprehensive geophysical programme, preliminary seismic refraction and resistivity surveys were carried out during December 1986, to determine the appropriateness of each respective method to the geologic materials of the Cheviot region;

E) In keeping with the aquifer evaluation programme extensive water quality analyses were conducted, simultaneously with pumping tests, comprising of approximately six full chemical and eight reduced chemical analyses; and

F) To conclude the work's programme a limited drilling programme was carried out at three sites in the region.

The majority of the larger farms in the Cheviot region have been handed down through families since the land was originally subdivided late in the nineteenth century. Consequently considerable information was obtained from farmers on the occurrence of springs, seasonal behaviour of streams and rivers and the location and performance of homestead supply wells.

Two engineering geological maps were drawn at scales which show in sufficient detail the structure, stratigraphy and lithology of the Cheviot region. Hydrogeological maps would also be produced at a reduced scale in order to show, in greater detail the hydrology of the two plains areas within the Cheviot region.

Of the 90 boreholes catalogued in September 1986, twenty-eight were monitored on a monthly basis by staff of the N.C.C.B, and periodically by the writer. In addition two permanent water level recorders were installed on suitable wells in each of the plain areas thus providing ideal benchmarks for water level records from other wells.

The boreholes used in the monitoring programme were surveyed with respect to mean sea level using local trig stations, before any piezometric contour map was constructed.

A monthly gauging programme was carried out at twenty-four sites along significant streams and rivers. These gaugings were supplemented with the installation of W-L' recorders on the Waiau and Jed rivers and Leamington Stream. The monitoring of bore water levels and the gauging of streams outlined above, was carried out by staff of the N.C.C.B. In addition, all significant springs in the region were identified, and where appropriate, gaugings of the springs and nearby streams were conducted by the writer on a monthly basis for twelve months.

Geophysical results from regions with similar geologic regimes, namely unconsolidated gravels with matrices of silts and clays overlying dense, massive mudstones at relatively shallow depths (less than 40 metres), on the Canterbury plains, indicated that a poor seismic contrast would exist in comparison to an excellent conductance contrast created in resistivity survey work.

Given the size of the Cheviot region twenty vertical electrical profiles were carried out. In the smaller of the two plains areas in the Cheviot region, Mina, the profiles were conducted on a north east trending line extending from the Swamp stream outlet area and from the outlet head of the Crystal brook stream. Both survey lines merged at the Cheviot township. It was hoped that firstly depths to bedrock and approximate thickness of aquifer material could be obtained and then secondly to identify areas of greater permeability.

The chemical analyses of the plains areas groundwater would determine its suitability for human consumption, irrigation and livestock and furnish a guide for the type and intensity of treatment required to make it potable.

Material descriptions and drilled samples were collected in areas where quantitative information was limited. The boreholes were of sufficient diameter to accommodate Ministry of Works and Development's downhole logging tools. The logging suite consisted of natural gamma, gamma-gamma and neutron nuclear logs.

' water-level

## 1.6 Thesis framework

This thesis is presented in five chapters. Chapter 2 describes the geology of the region based on previous publications, air photo interpretation and field mapping of the Cheviot basin with emphasis on the Spotswood and Mina Plains and proposes a physical model for the formation of Quaternary material deposits. Chapter 3 extends the classification and mapping of Chapter 2 with the application of surface and subsurface geophysical investigations which provide a qualitative comparison of the aquifer materials of both plains. Chapter 4 describes the surface and subsurface hydrology of the region based on a comprehensive monitoring and gauging programme carried out during the November 1986 to November 1987 period. Chapter five contains the conclusions drawn from Chapters 2 to 4.

# 2.0 GEOLOGY

## 2.1 Introduction

The main objective of this study is to determine the hydrology of the region within a geological context. Quaternary materials of the Cheviot region have historically and will in the future yield greater quantities of groundwater than Pre-Quaternary lithologies, consequently the emphasis of this the geology chapter, must be within the materials of the Quaternary.

The first section of Chapter 2 presents a general summary of Pre-Quaternary stratigraphy and site development of Cheviot basin. The second section is based on air photo interpretation and field mapping work carried out during the course of this study and examines materials which have been deposited during the Quaternary Period within the Cheviot basin and their provenance with particular emphasis on the alluvial materials within Mina and Spotswood plains.

The correlation of specific aggradational and degradational terrace surfaces in Mina and Spotswood with particular climate subdivisions has not been attempted due to the absence of age control.

## 2.2 Previous work

The earliest report on the pre-Quaternary geology was made by Haast (1865) who documented general field observations of the Cheviot region.

Hutton (1877) presented a geological report in which he proposed that the intermontane valleys which characterized the region and similar regions to the south (Rakaia) were remnants of ancient river courses. He suggested that limestones were deposited in seas which filled valleys similar in form to those of the present day. After the Tertiary marine sequence was deposited recession of the sea allowed an erosional cycle to recut the valleys leaving remnant Oligocene sediments.

McKay (1902) presented a ninety page report on the Cheviot county and Amuri district, detailing structural damage to the township of Mackenzie (now Cheviot) and stratigraphic features which resulted from the earthquake which occurred in 1901. He determined that the origin of the earthquakes were not due to fresh rupture along the northern part of the Kaikoura line of fault but that the greater force of the earthquake was manifested along a line nearly parallel to the Great Clarence fault.

McKay predicted in his conclusions that since there had been no serious disturbance of the Cheviot region for fifty years it was reasonable to conclude that a like period would pass before the district was 'violently disturbed by equivalent earthquake action'. McKays prediction proved correct to within a year, when the region experienced a scale 5 intensity earthquake (Modified Mercalli Scale, Hayes 1951), centered in the Cheviot basin at 10.41 am 6th February 1950.

In Cotton's (1916) discussion he suggested that the intermontane Hurunui - Waiau region previously described by Hutton (1887) was formed as a consequence of faulting and compression of basement (Mesozoic) in which the covering strata (early to mid Tertiary) were thrown into folds during the late Tertiary. Further Cotton proposed a theory of antecedence for the origin of the major rivers in the region like the Hurunui, in which the rivers had developed courses during regional uplift in the Pliocene.

Speight (1915) also dealt in some detail with the structural features of Hurunui valley, 8 km south of the Cheviot basin, the development of the course of Hurunui River and the glacial features of the upper Hurunui Valley in the Ethelton area (Fig 1.1).

Marwick (1928) reported on mud flows which occurred in the bed of the Leamington Stream 18 km west of Cheviot township in 1927. Marwick did not make a detailed study of the area concluding in the report that the flows were related to 'some form of fault related activity'. The mud flows were most likely related to movement on the active Kaiwara fault, the nature of which is uncertain.

After a study of the Cheviot district Henderson (1921) produced a sketch map of the geology at a 1:150,000 scale. His discussion concluded that the plains surfaces within the Cheviot basin were formed during a period of standstill when the land was about 30 metres lower than at present based on the extensive raised terraces which occur 28 to 40 metres above present level along the Jed River.

With the exception of a paper on the break in the Tertiary strata near the Hurunui River mouth nothing was published on the Cheviot region until 1962 when Powers (1962) mapped the river terraces along the course of the Hurunui River. Powers examined several river terraces and attempted a correlation of river aggradation and glacial advances based on extending present river profiles to profiles of moraines in the upper reaches of the Hurunui River.

The only other publication on the study area is the Geological map produced by Gregg (1964). He mapped the rocks and materials of the region at 1:250,000 scale but has apparently based his work largely on previous publications.

## 2.3 Pre-Quaternary geology

### 2.3.1 Stratigraphy.

Pre-Quaternary lithologies have traditionally been divided into two major units (Gregg 1964), thus (Fig 2.1);

(1) Mesozoic rocks.

The coastal geological unit of the Mesozoic is the Torlesse Supergroup (after Warren 1967). These lithologies form the mountainous ranges basement of the Cheviot basin.

Gregg (1964) mapped the iithology of the Torlesse group within two units of overlapping age (Appendix 2.1), the first older unit mapped as Balfour to Kawhia Series and a younger unit, Herangi to Oteke Series based on sparse fossils, supported by differences in induration.

Andrews et al (1976) describe the Torlesse terrain as consisting of blue grey, moderately to strongly indurated, mostly graded bedded, poorly sorted quartzo feldspathic sandstone and argillite with minor chert, marble, conglomerate and volcanics.

Smale (1978) carried out mapping of a younger part of the Torlesse terrain the Ethelton Conglomerate which outcrops along the banks of the Hurunui River near Ethelton. Smale described the conglomerate as approximately 150 metres of lithic feldsarenite with pebbles of quartzarenite, quartz lutite, rhyolite and lutite.

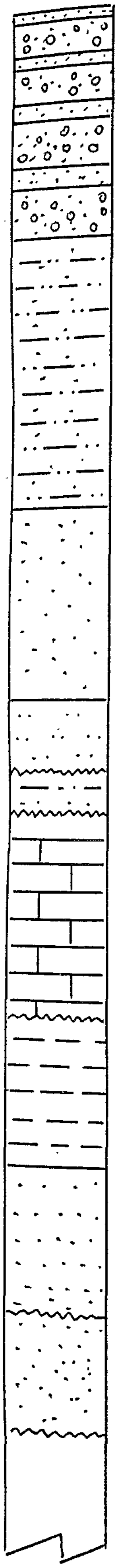
(2) Tertiary rocks.

Unconformably overlying the Torlesse Supergroup are a diverse range of formations which have been recently grouped by Browne & Field (1985) into three groups (Fig 2.1);

(i) Eyre Group: The Eyre Group was defined by MacPherson (1947) and subsequently by Andrews et al (in prep) and ranges from Haumarian to Whaingaroan age. Within the study area it outcrops extensively along the eastern boundary of the coastal Caverhill Ranges.

Of the seventeen Formations recognized from the Group in Northern Canterbury three have been correlated for the coastal northeast region

Fig 2.1. Stratigraphic column for Cheviot coastal region. Pre-Quaternary geology based on Browne & Field (1980)



| UNIT | | NEW ZEALAND STAGE | SERIES | |
|---|---|---|---|---|
| Mina Spotswood<br>M2 — S3<br>— S2<br>M1<br>— S1<br>Mo — So<br>FORMATION | GRAVELS- unweathered, compact, medium, grey/brown, coarsely layered, poorly graded gravels of predominantly greywacke clasts up to 14cm, some chert, Jasperlite, clasts within a silty sand matrix, overlain by dry, hard, yellowish brown, massive clayey silt with some sand (loess) | Otira glaciation<br>Waimea glaciation | HAWERA | QUATERNARY |
| GRETA FORMATION | • Blue grey, moderately indurated, calcareous, bioturbated, micaceous, fine to very fine sandy mud stone | Mangapanian | WANGANUI | TERTIARY |
| MT BROWN FORMATION | • Medium brown, soft to moderately indurated, calcareous and noncalcareous, massive to moderately laminated, micaceous, lithic, medium to fine sandstone | Tongaporutuan | SOUTHLAND | |
| WAIKARI FORMATION | • Sandstone and siltstone | Waitakian | PAREORA | |
| SPY GLASS FORMATION | • Alternating calcareous sandstone, limestone and mudstone | Runangan | | |
| AMURI LIMESTONE | • centimetre to decimetre bedded light cream to light blue cream, indurated bioturbated, fine sandy micrite. | | ARNOLD | |
| ASHLEY MUD STONE | • Sandy siltstone with subordinate intercalated sandstone | Kaiatan | DANNEVIRKE | |
| WAIPARA GREEN SAND | • Medium grey green, indurated, noncalcareous to slightly calcareous, siliceous, richly glauconitic, mod. sorted quartzose sandstone | Upper Teurian | | |
| CONWAY FORMATION | • Alternating metre to decimetre bedded sandstone | Middle Teurian | MATA | |
| TORLESSE SUPERGROUP | • Blue grey, moderately to strongly indurated, mostly graded bedded, poorly sorted quartzo feldspathic sandstone. | | | MESOZOIC |

near Cheviot. The oldest unit, the Conway Formation unconformably overlies basement and is described as consisting of silty fine to medium sandstone to sandy coarse siltstone (Browne & Field 1985). The Conway Formation is unconformably overlain by the Waipara Greensand (first detailed by Thompson 1920) a massive and cross bedded greensand. The third unit is the Ashley mudstone (after Mason 1941) which has been described in the Hurunui area (Maxwell 1964) as consisting of sandy siltstone with subordinate intercalated sandstone.

(ii) Late Cretaceous to Mid Oligocene Limestone: The Amuri Limestone Formation (modified in Browne & Field 1985 after Hutton 1874) is named from Haumuri Bluff and is defined as centimetre to decimetre bedded, light cream, indurated, bioturbated calcilutite. The age of this formation at Gore Bay and Hurunui River mouth is Kaiatan to Runangan.

(iii) Motunau Group: The Motunau Group rest unconformably on the Amuri Limestone Formation and encompass a diverse range of largely non - volcanogenic sediments. Four formations are exposed in the Cheviot region within this group.

The formations are described thus (after Browne & Field 1985);

- Spy Glass Formation, a very fine sandy wackestone, packestone and very calcareous very fine to medium sandstone.
- Waikari Formation, a sandstone and siltstone.
- Mt Brown Formation, a sandstone, siltstone, conglomerate, limestone and mass flow conglomerate.
- Greta Formation, the type section for this formation is designated as the 400 metre thick section in Cobbolds Creek, Greta River, from the conformable contact with Mt Brown Formation to the highest Tertiary outcrop. In the Cheviot region the formation outcrops extensively and consists of up to 400 metres of blue grey, moderately indurated, calcareous, bioturbated, micaceous, fine to very fine sandy mudstone, with a number of localized facies variations which range from conglomerates, pebbly sandstones and coquina limestones.

The formation locally contains upto 1 metre diameter calcareous concretions. It is largely massive but faint horizontal stratification is evident on some unweathered surfaces. Maxwell (1964) stated that the formation was deposited in quiet water, probably on the continental shelf or slope and is of Tongaporutuan age.

### 2.3.2 Geological History

Within the Hurunui River-Omihi area late Cretaceous non-marine rocks (Conway Formation) rest unconformably on metamorphosed Torlesse Supergroup rocks indicating a change in the tectonic regime in the Northern Canterbury region. This regional unconformity coupled with the absence of early to mid Cretaceous rocks indicates that there was a major stratigraphic break between strongly deformed basement and weakly deformed cover during which the whole region was deformed by the Rangitata Orogeny (Suggate 1968). However there is some debate as to whether there was continuous sedimentation throughout the late Jurassic to late Cretaceous period based on observations in some sections within New Zealand of no pronounced stratigraphic break (Bradshaw 1980). Unfortunately it is beyond the scope of this study to address this question with any further discussion.

Towards the end of the Cretaceous the sea slowly trangressed over the coastal regions submerging Northern Canterbury. Deposition of marine sediments ranging from sandstones, silts, lignite, greensands and limestones continued throughout the Tertiary and was interrupted only by brief periods of volcanic activity. The relative thinness of the Amuri Limestone Formation in the Waiau-Hurunui region compared to thickness of this formation to the south indicate that the land occupied by these valleys was the last to be invaded by the sea during submergence (Browne & Field 1985).

In the latter Pliocene the intensely deformed belts of Mesozoic rocks which constitute the mountain ranges flanking the Cheviot basin were formed. The rate of uplift, folding and faulting must have been comparatively slow enough to allow the main tributaries of the area namely the Waiau and Hurunui to maintain flow through antecedent gorges across the older mass of the upthrown blocks (Yousif pers comm 1987).

By the end of the Pliocene to Early Pleistocene the basis of the independent intermontane basins within the Waiau and Hurunui region was forming and would continue to do so throughout the Quaternary.

## 2.4 Quaternary Geology

### 2.4.1 Terminology

The Quaternary period is traditionally divided into two intervals of epoch status, the Pleistocene and the Holocene (Eicher 1976). As the Holocene also coincides with the end of the last glacial phase it is often referred to as the postglacial.

### 2.4.2 Stratigraphy.

The origin of the alluvial material within the Cheviot basin can be interpreted in terms of a hypothesis of antecedence where the Waiau River, Leamington Stream, Crystal Brook and Swamp Streams were linked to approximately five periods of tectonic and climatic base level change. These periods are represented by multiple periods of aggradation, lateral channel migration and the modern flood plain in the Spotswood and Mina Plains.

(1) The Spotswood area

Four lateral terrace surfaces were mapped in the Spotswood area on the basis of relative position to each other and respective elevation (Fig 2.2), namely $S_0$, $S_1$, $S_2$ $S_3$. Unfortunately the age of each surface has not been determined by absolute dating methods and consequently each surface has been assigned a letter classification which indicates a relative position within a stratigraphic sequence.

(i) The $S_0$ Surface

The $S_0$ Surface represents the oldest aggradational event within the Cheviot basin. Within Spotswood it was mapped in two areas, namely a relatively narrow strip of terrace surface 200 to 350 metres wide which extends in a north easterly direction along the scrap of McPherson and Caroline Streams and secondly as a remnant surface extending along Leamington Road to 200 metres north of the intersection of Leamington and Waiau West Roads. The gravels that form this surface lie unconformaly against Tertiary rocks and expose a high angle normal fault.

Type sections for the $S_0$ surface in this area are designated atop of the most northern Spur range in Sinclair Downs (grid ref 557-466) and along the scarp of McPherson Stream (grid ref 599-496).

The $S_0$ terrace is composed of 3 to 4 metres of fluvatile derived weathered, compact, medium grey to brown gravels of predominantly greywacke clasts upto 12 centimetres in diameter within a silty sandy brown matrix. The lower unconformable contact on Greta Formation is sharp and slightly weathered. The gravels are overlain by 1 to 2 metres of dry, hard, light yellowish brown, massive, clayey silt with some sand.

The $S_0$ terrace has been uplifted throughout the Quaternary to a mean elevation which is outside the recharge of any present tributaries consequently the unit has a very poor potential for groundwater extraction which is reflected in the absence of bores within this unit.

(ii) The $S_1$ Surface

The $S_1$ Surface extends north eastwards from the southern limits of the Spotswood region near Downs Road/Phoebe to Waiau West Road areas in the lower portion of the plains.

An ideal section for this unit is designated within Harrisons Stream at the streams intersection with State Highway 1 (grid ref 586-499). The outcrop is composed of slightly weathered compact, light brown, coarsely layered, poorly graded gravels, predominantly greywacke clasts upto 8 centimetres long within a silty sand matrix. The lower contact is not exposed at this section. The gravels are overlain by an unweathered dry, hard, light yellowish brown, massive, clayey silt with some sand the upper contact is sharp and slightly weathered.

Four bores have been drilled within this unit (Appendix 2.2), none encountered the underlying Greta Formation thus indicating that the gravels are greater than 30 metres thick in the central region of the terrace (bore reference N33.86).

(iii) The $S_2$ Surface

The $S_2$ Surface extends along the western and eastern flanks of Leamington Stream from the Downs Road bridge to 150 metres south of Waiau West Road. South of Downs Road bridge the terrace has been completely eroded as the region has experienced continual uplift associated with tectonic activity on the Kaiwara Fault (Fig 2.2).

Material descriptions were not recorded for the two bores drilled within this unit and as the lower contact is not exposed the total thickness of this unit is not known.

(iv) The $S_3$ Surface

The $S_3$ terrace surface flanks the present floodplain of the Waiau River. Over twenty bores have been drilled on this surface as it has proved to be an excellent groundwater producer. The most recent bore drilled in this unit was a County supply well in February 1987 by the Ministry of Works and Development (Appendix 2.2). Drilling showed that the material was composed of unweathered, moderately well sorted, well rounded predominantly greywacke clasts upto 14 cm long with occasional crystalline rock clasts within an unconsolidated matrix of sandy gravel with some silt. The sandy gravels were overlain by 2.5 metres of unweathered clayey silt with some sand.

(2) The Mina area

Three terrace surfaces have been mapped in the Mina area, the first $M_0$ is correlated with the $S_0$ surface described in the previous section (Fig 2.3).

(i) The $M_0$ Surface

The $M_0$ Surface occurs as terrace remnants within the Sinclair Downs area which appear to be of similar elevation and physiography to the terrace surface $S_0$ mapped in the Spotswood area (Fig 2.2).

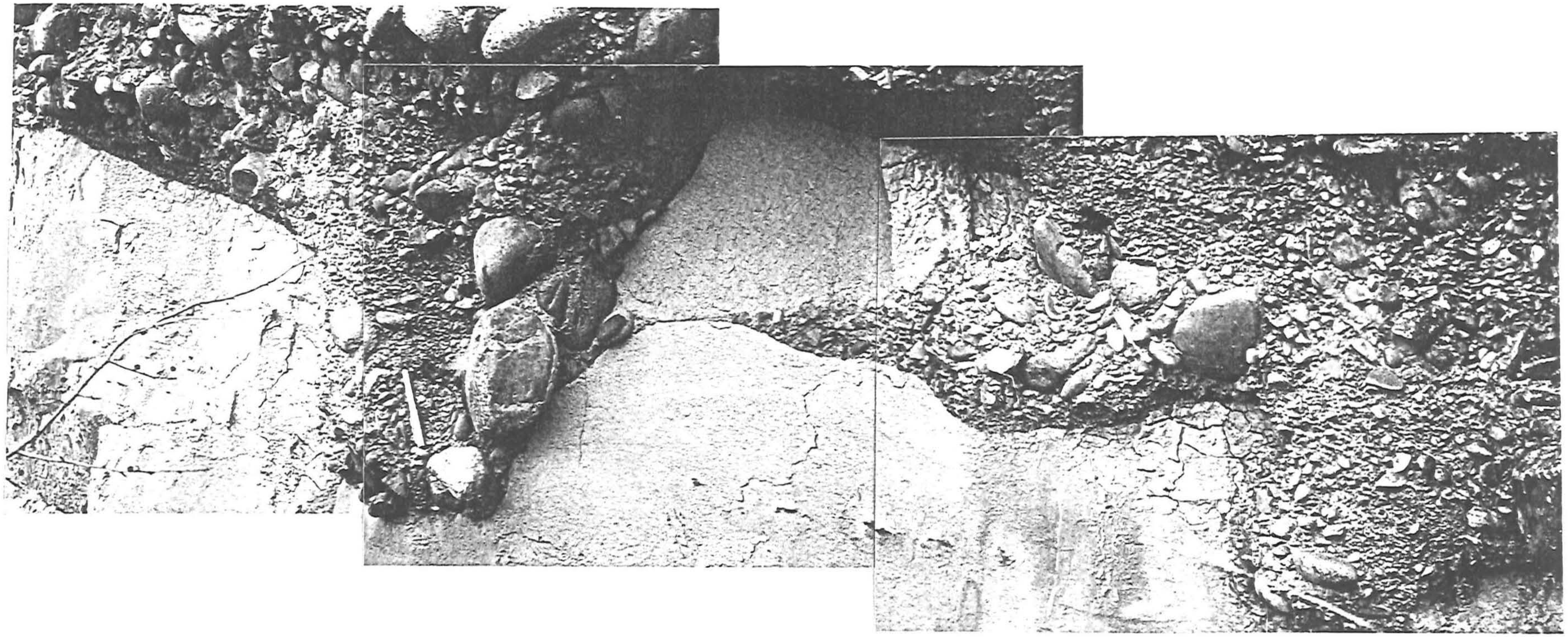
The lower contact of the $M_0$ unit is clearly exposed along the northern bank of Swamp Stream and in particular at grid ref 551-441 (Fig 2.4). The gravel section consists of slightly weathered to weathered, dry, compact, light greyish brown, coarsely layered, poorly graded sandy gravels of greywacke clasts with occasional chert and Jasperlite clasts. The bottom contact is sharp and slightly weathered. The section is overlain by 1.5 metres of silty clay with some sand (loess).

(ii) The $M_1$ and $M_2$ Surfaces

The $M_1$ Surface does not occur in the Mina area but entrenchment by Swamp Stream has exposed a section which indicates the present Mina Plains formed from two periods of aggradation. The most extensive exposure exists at grid reference 551-450, approximately 400 metres downstream of the main trunk railway near Swamp Stream (Fig 2.5).

The $M_1$ unit consists of 5 metres of slightly weathered, compact, light greyish brown very coarsely layered, crossbedded, poorly sorted coarse silty gravels overlain by 4 metres of slightly weathered, firm, light yellow/brown, massive clayey silt (loess). The lower contact with

Fig 2.4. Basal contact of unconsol-idated alluvium (MO unit) on bedrock (Greta Formation) show- channel development (Grid ref 551.441)



centimetres
20
10
0
SCALE

the Greta Formation is sharp and slightly weathered. Within the loess layer a 1.5 metre lens of silty gravels was mapped which indicates a period of degradation where significantly smaller streams relative to aggradational events flowed on a loess covered plain.

The $M_1$ unit is directly overlain by a subsequent aggradational unit which forms the present Mina Plains surface, the $M_2$ unit. The $M_2$ unit consists of 1.75 metres of sandy coarse gravel very similar to that described in the $M_1$ unit, overlain by 1 metre of silty clay.

The $M_1$ and $M_2$ units which make up the Mina Plains have had over thirty groundwater supply bores drilled by landowners since the 1850's when the land was first settled. Material descriptions have been recorded for eight bores, six of the eight records describe drilling into the Greta Formation at depths ranging from nine to sixteen metres (Appendix 2.3). The most recent bores, references N33.176, N33.177 and 033.74 (Fig 2.3) were drilled in August 1987. The material descriptions showed that the gravels are on average 14 metres thick in the upper portion of the plains and thin towards the east to approximately 2.5 metres.

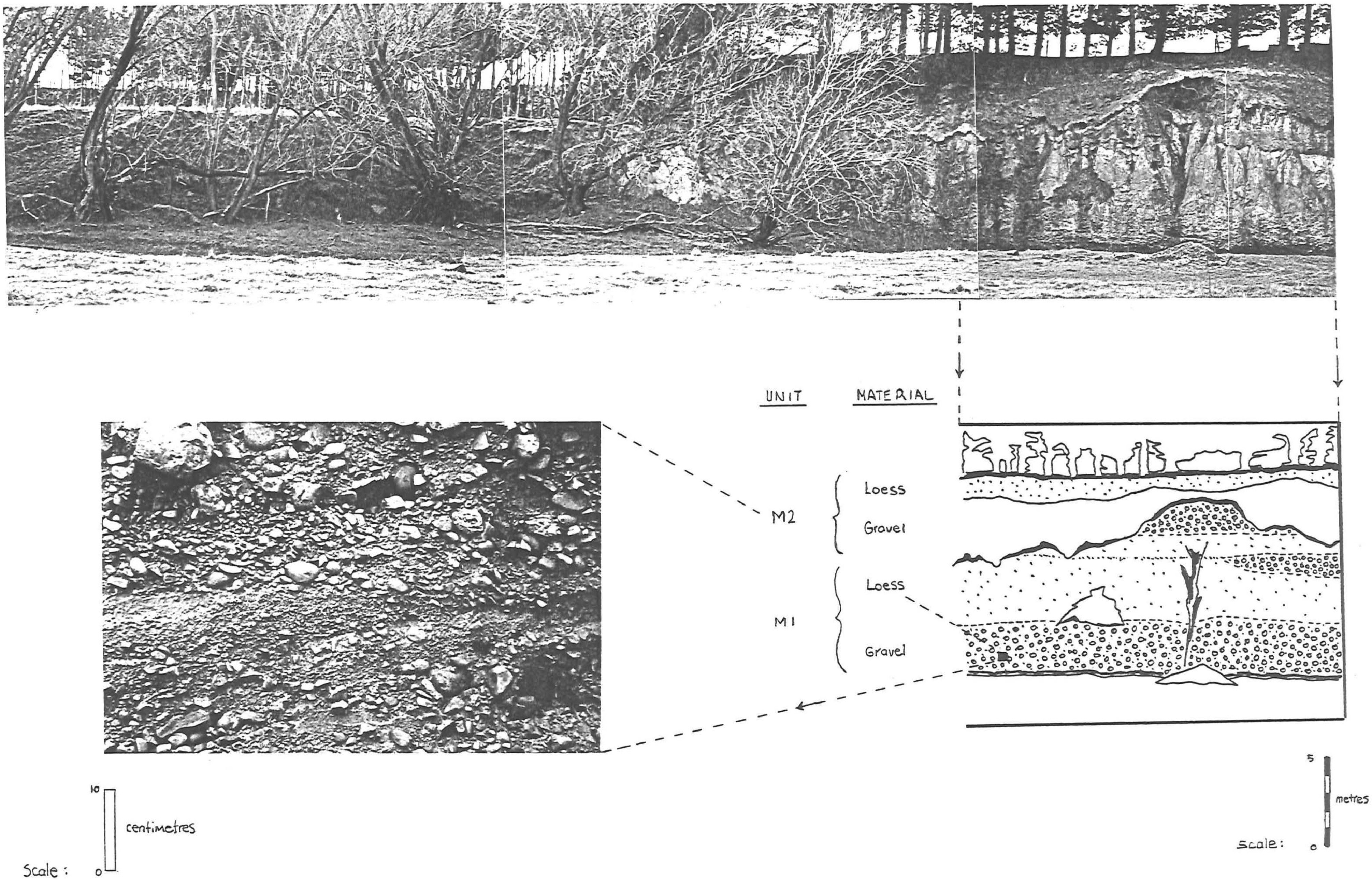
2.4.3 Structure

The Cheviot basin lies in a belt of active faulting involving both Mesozoic and Tertiary rocks which is considered to have initiated at the beginning of the Quaternary.

The Kaiwara Fault is the most dominant fault in the region. It has been mapped trending in a north east direction from Waikari to the south to the Mendip Hills near the Conway River (Gregg 1964) along the western boundary of Cheviot basin. From preliminary air photo interpretation the fault is considered class 1 active with a dominant oblique slip movement with significant horizontal displacement associated with extension perpendicular to the strike of the fault.

It is considered highly probable that a similar fault to the Kaiwara Fault exists along the eastern boundary of the Cheviot Basin at the base of the coastal ranges, however outcrop in this region is limited due to recent aggradational events during the late Quaternary which have masked any obvious fault trace. However Henderson (1921) did include a fault trace along the entire eastern boundary based on observed extensive crush

Fig 2.5. Cross section showing two units (M1 & M2) of fluviatile alluvium overlain by loessic deposits near Swamp Stream, Mina Note the coarse layering and cross bedding evident in the poorly graded alluvium.


UNIT
MATERIAL
M2
Loess
Gravel
M1
Loess
Gravel
10
centimetres
Scale :
0
5
metres
scale:
0

zones near Mt Caverhill range. The fault trace was not included in Gregg's (1964) geological map of the region, Gregg mapped the Hundalee Fault as a concealed Fault only in the most northern portion of the basin to the north of Parnassus. To map this fault would require considerably more field work than this study permits.

Based on aerial photo interpretation and surface mapping two previously unrecorded faults have been mapped in the north east corner of Spotswood (Fig 2.2). Both faults show steeply dipping dip slip displacement and represent surface rupture associated with mid to late Quaternary tectonic activity on the Kaiwara Fault.

### 2.4.4 Geological History

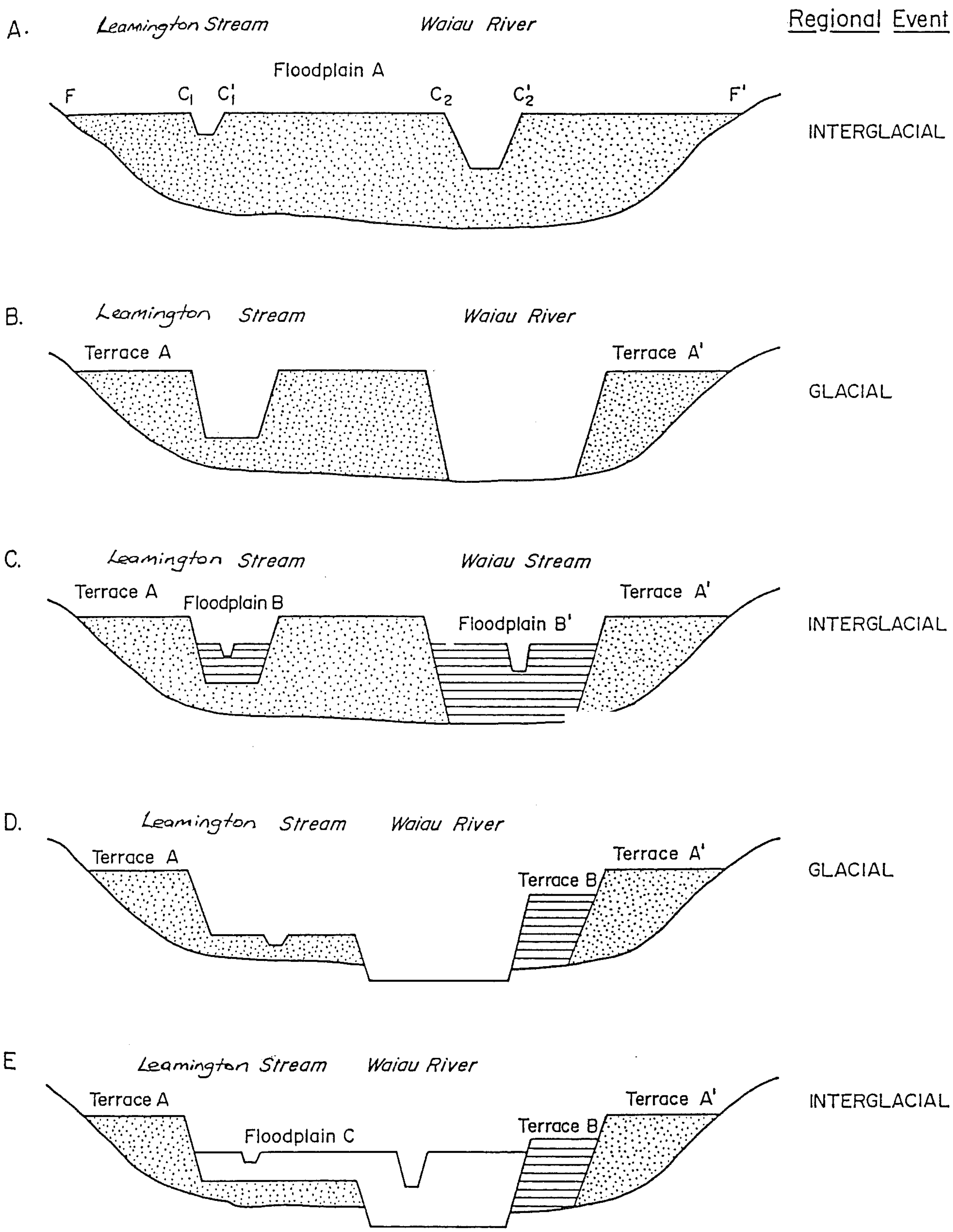
The downstream effects of changing sea level and bedload/discharge ratios resulting from cyclic climatic fluctuations have played an significant role in determining the morphology of streams and character of the sediments delivered to the Cheviot basin.

Only two rivers, the Waiau to the north and the Hurunui to the south have maintained an antecedent course through the faulted Mesozoic and early Cretaceous ranges which bound the Western margin of the Cheviot basin. It appears unlikely that the Hurunui has at any stage entered either the Mina or Spotswood plains areas because of a physiographic barrier of Tertiary lithology which exists along the southern margin.

Both the Spotswood and Mina Plains were formed by multiple glacial outwash and interglacial alluvium material associated with at least five major cyclic climatic fluctuations (Fig 2.6). The source areas for the Waiau and Hurunui Rivers were strongly glaciated and several glacial lakes including Sumner, Sheppard and Taylor are ponded by glacial moraines.

In general terms the sea level would fall during glacial periods and extending the shore line to the edge of the continental shelf the local rivers would incise and loess would have accumulated in the Cheviot region (Fig 2.7). In interglacial stages the sea level would rise significantly and rivers would entrench from the Southern foothills transporting alluvial material to the coastal basins such as Cheviot (Fig 2.8).

Fig 2.6. Schematic of the development of fluvial terraces by lateral dis-placement of the channel and by cut and fill processes in the Spotswood Plains (adapted from Chorley 1985)


A.
Leamington Stream
Waiau River
Regional Event
Floodplain A
F
$C_1$
$C_1'$
$C_2$
$C_2'$
F'
INTERGLACIAL
B.
Leamington Stream
Waiau River
Terrace A
Terrace A'
GLACIAL
C.
Leamington Stream
Waiau Stream
Terrace A
Floodplain B
Terrace A'
Floodplain B'
INTERGLACIAL
D.
Leamington Stream
Waiau River
Terrace A
Terrace A'
Terrace B
GLACIAL
E
Leamington Stream
Waiau River
Terrace A
Terrace A'
Floodplain C
Terrace B
INTERGLACIAL

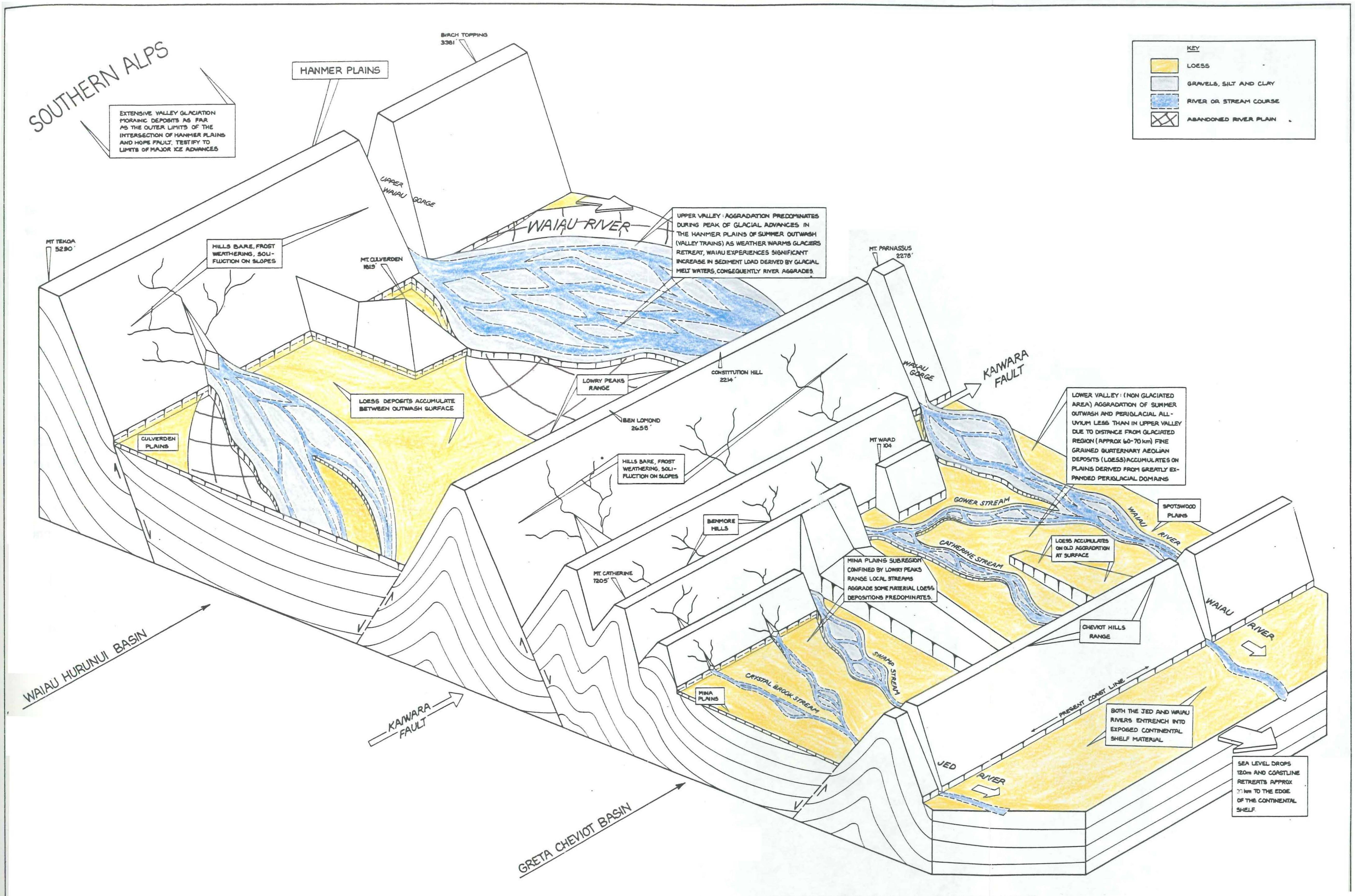



FIG 2·7

A: PHYSICAL MODEL:- GLACIAL-PERIGLACIAL

Waiau - Hurunui Region

The Waiau on the other hand has played a significant role, together with Leamington Stream in the formation of the Spotswood plains. Again it is unlikely that it has ever entered the Mina Plains due to the radial constraint imposed on it by the narrow gorge from which it emerges.

Within the Mina plains fluvial sediments have been laid down by the substantially smaller Swamp and Crystal Brook Streams sourced from catchment immediately to the west of Mina. Although the tributary streams in the Mina Plains area are smaller and flow over a stream course of the order of several kilometers in comparison to the tens of kilometers of the Waiau River the source geology for both the Mina and Spotswood Plains is similar, namely Torlesse, Eyre/Motunau Group and Tertiary greywacke clasts, conglomerates, siltstones and mudstones.

The Mina plains have been formed by an succession of alluvial fans which have built up from the Swamp Stream and Crystal Brook Stream outlets from the west. The dominant stream morphology would have been braided as each stream coalesced onto Mina Plains.

The resultant facies would show an gradation from boulder beds to conglomerates to pebbly sandstones to siltstones. An alluvial fan is typically poorly sorted due to torrential deposition especially near the fan head , becoming better sorted and finer grained away from the source, exhibiting a complex of cross bedding and flow structures, together with graded bedding (Chorley 1985).

This physical model has been validated by test drilling carried out in August 1987. Borehole logs from N33.176 and N33.177 drilled in the upper part of the fan showed that the dominant material was in fact boulder beds and conglomerates within a silty clay matrix. In contrast the borehole log from N33.74 drilled at the lower part of the fan showed well sorted pebbly sandstones (Appendix 2.3).

The dominant river/stream morphology of the Waiau and Leamington tributaries in the Spotswood/Parnassus plains during periods of aggradation was braided. Typically braided river systems consist of individual channels of low sinuosity which are constantly subdividing and shifting their position as the result of the building of longitudinal sand bars

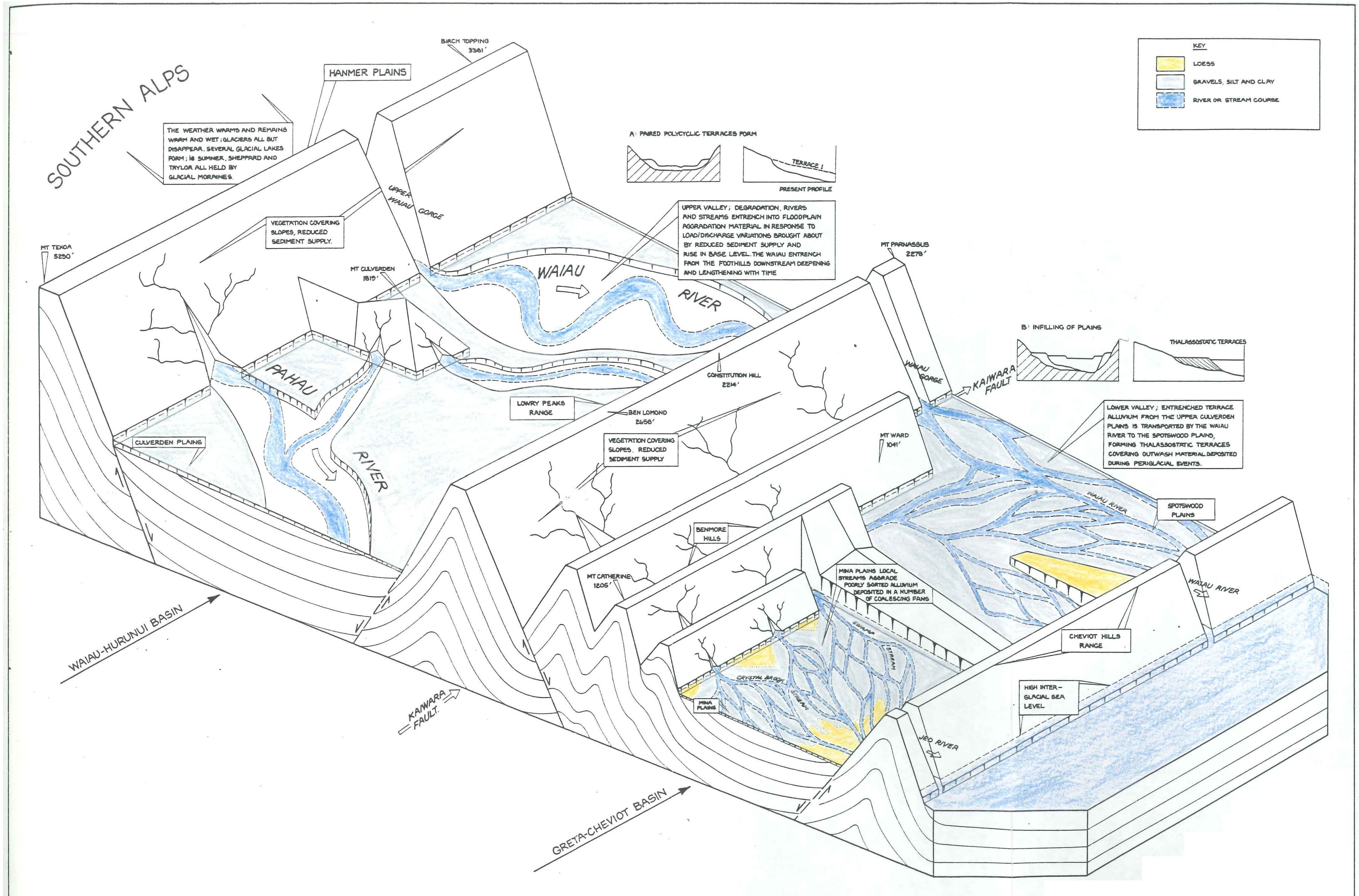



FIG 2·8

B: PHYSICAL MODEL: INTERGLACIAL

Waiau-Hurunui Region

with horizontal bedding and of transverse bars with planar cross-bedding. The resultant facies present a complex aggradational association of channel lag deposits, overbank finer material and crossbedded and rippled sand bar material (Chorley 1985). There would be a tendency to form a series of lenses of gravel and sand, each more extensive in the direction of flow than transverse to it. The better sorted deposits of the Spotswood plains, especially in channel deposits are of higher permeability, explaining the higher incidence of better yielding wells in Spotswood than in Mina.

# 3.0 GEOPHYSICAL INVESTIGATIONS

## 3.1 Introduction

Geophysical methods provide both qualitative and quantitative data on subsurface conditions in a wide range of rock and soil materials (see Sharma 1976, Bhattacharya et al 1968, Koefoed 1979, Dobrin 1982). The decision as to which method should be applied is based on the objectives of the study and the materials present.

Three geophysical techniques have been utilized as part of this hydrogeological study in the Cheviot region, including;

(1) Seismic refraction: Although no previous seismic refraction work had been carried out near Cheviot, several surveys have been conducted in the Canterbury region on similar materials (Broadbent & Haines 1973, Broadbent 1978). Previous results obtained indicated that the seismic refraction method is poor for determination of gravel properties and variations in areas where gravels are underlain by marine beds.

(2) Electrical resistivity: As with seismic refraction, no previous electrical resistivity surveys have been conducted at Cheviot, however the applicability of this method in the location of hydrogeologic targets of interest in unconsolidated material is well documented (Kelly 1977, Urish 1981, Kelly & Kosinki 1981, Kwader 1981, Mazac & Landa 1985, Huntley 1986).

The unconsolidated gravels, silts and clays which make up the plains areas of the Canterbury region have consequently been studied in a number of resistivity surveys, (Risk 1974; 1979; 1982, Callander & Broadbent 1985) and useful data obtained.

After successful initial trial surveys as part of this project a comprehensive resistivity programme was undertaken, 28 further soundings were completed in 1987.

(3) Nuclear bore logging: The third geophysical method applied in the Cheviot study area included a suite of nuclear logging tests comprising of natural gamma, gamma-gamma and neutron logs. Four bores were selected for running of this logging programme: two bores are located in the

Spotswood plains area, and two additional bores were chosen in the Mina plains area.

## 3.2 Seismic Refraction Survey

In an attempt to establish the applicability of the seismic refraction method to materials in the Cheviot region two trial profiles were completed using a single channel hammer and plate seismic refraction unit.

Mapping of the Cheviot Basin had revealed unconsolidated gravels (aquifer) overlying massive silty mudstone (bedrock). In order to obtain typical seismic velocities for the respective materials two profiles were run. At the first locality (grid ref 471.575) mudstone is known to be within two meters of the ground surface; at the second locality (grid ref 491.551) gravels are more than 20 meters thick, a depth beyond the range of the single channel seismic unit available thus allowing for determination of seismic velocity of the gravels.

The analysis of profile data followed Hawkins method (1961). The results from both profiles are presented in Appendix 3.1. The calculated velocity for the bedrock mudstone at site #1 is approximately 1080 $ms^{-1}$. The calculated velocity at site #2 for surfical gravels is approximately 1135 $ms^{-1}$, (see Palmer (1980) for methods of interpretation). As the gravels have a slightly higher velocity, velocity inversion will occur and refracted rays are unlikely from the gravel-mudstone contact. Consequently the seismic refraction was considered inappropriate and was not used further.

## 3.3 Direct Current Electrical Resistivity Surveying

### 3.3.1. Introduction

The Schlumberger electrode array (see Keller & Frishknecht 1966) was used for each of the twenty-eight resistivity soundings carried out on alluvial plains surfaces in the Cheviot region. This array was chosen in preference to other established methods like the Wenner electrode array because;

(1) One of the principle assumptions in electrical resistivity interpretation is that the subsurface layers are electrically homoge-

neous, in practise however layers are often electrically inhomogeneous. If inhomogenieties lie close to the position of the potential electrodes, distortion of the pattern of current flow occurs and the measured potential difference is falsified. Although falsification occurs both in the Schlumberger and Wenner configurations, the fact that the potential electrodes are displaced for each new measurement in the Wenner configuration make it difficult to account for in the interpretation. (Koefoed 1979). In the Schlumberger configuration the position of the potential electrodes is maintained throughout a series of measurements so that similar errors occur on all measurements. The predictable aspect of the errors is therefore easier to account for in the interpretation.

(2) Computer programmes available at the North Canterbury Catchment Board which enable rapid curve matching based on the Schlumberger array configuration.

3.3.2. Theory

The theoretical foundations that deal with current flow in a horizontally stratified earth are well documented, (see Bhattacharya & Patra 1968, Sharma 1976, Koefoed 1979). To assist in the understanding of interpretation techniques discussed later in this chapter, some of the basic concepts are discussed.

The property of electrical resistance of a material is usually expressed in terms of its resistivity. If the resistance between opposite faces of a conducting cylinder of length L and cross sectional area A, is R, then the resistivity is expressed as; (after Sharma 1976)

$$\rho = \frac{R \times A}{L} \qquad \text{Equation 3.1}$$

The S.I unit of resistivity is ohm.m

The conductivity of a material is defined as the reciprocal of its resistivity and measured in Siemens (ohm spelt backwards).

The fundamentals of current flow in an earth layer will be introduced but the theory which forms the basis for potential measurement in a homogeneous medium due to a point source of a current should be referred to in one of the references cited above.

The simplest approach to introduce the fundamentals of current flow in the earth is to consider the current flow in a completely homogeneous isotropic earth where each of the layers is of uniform resistivity. Take a layer of length L, resistance R, through which a current I is flowing. The potential difference across the ends of the resistance is given by Ohm's Law, where,

$$V = R \times I \qquad \text{Equation 3.2}$$

and by definition of equation 3.1, equation 3.2 can be re-written, (after Sharma 1976)

$$V / L = \rho \times I / A$$

$$\text{so} \quad \text{grad } V = \rho \times i \qquad \text{Equation 3.3}$$

where grad V stands for the potential gradient, and i is the current density per unit of cross-sectional area.

### 3.3.3 Method of measurement

All soundings were carried out with the Ministry of Works and Development older ABEM terra resistivity unit. The Schlumberger electrode array consists of four collinear symmetrically arranged electrodes AMNB, with each pair AB and MN having a common center. A sounding consists of a set of measurements made when the electrode pair AB are expanded about a fixed center point. The spacing between the center of the array and the outside current electrode (AB/2) is expanded logarithmically from AB/2 at 1 metre. As the depth penetration of a sounding is predominantly controlled by the distance between the current electrodes (Koefoed 1979) in areas where the depth to bedrock is approximately 15-25 meters, the AB/2 distance would only generally be required to be expanded to 125 meters. In areas where bedrock is deeper the AB/2 distance will be greater. The measured resistivities become more representative of conditions deeper within the ground as the distance between the current electrode is increased. Near surface variation in resistivities will be readily detected, however at greater depths an average resistivity of all layers will be measured.

The distance MN is also increased as the distance between the current electrodes increase. If MN were not increased the potential difference would become too small to allow a reliable measurement. Steel spikes are used as current electrodes and $Cu/CuSo_4$ porous pots as potential electrodes. Currents ranging from 20-50 milliamps are generated as a square wave a by 12volt battery. The potential 'V' produced between the potential electrodes is measured using a receiving unit.

Each set of field data is used to calculate an apparent resistivity of the subsurface;(after White 1985)

$$\rho_a = k \times V / I \qquad \text{Equation 3.4}$$

where $p_a$ = apparent resistivity

V = potential difference between electrodes M and N

I = current between electrodes A and B

k = a geometric factor dependent on the configuration of the electrodes.

3.3.4 Interpreting field data

Data measured during a sounding is presented as a plot of apparent resistivity against AB/2 on log-log paper (Fig 3.1). Having constructed the sounding curve the two layer earth model curves were used to obtain a best fit match for successive sections of the sounding curve thereby attaining a representative model of the layers directly beneath the sounding site. A summary of this technique prepared by Broadbent (1987 unpub internal document Ministry of Works and Development, Christchurch) greatly assisted this initial interpretation stage.

The initial models are then further refined with the aid of the computer programmes (held by the North Canterbury Catchment Board), which match at very high speeds the initial interpretation with other interpretations it has stored in its memory based on the data of the sounding. The interpreted model is then conveniently presented in the form of a geoelectric section which shows inferred layer resistivities and thickness (Fig 3.1).

3.3.5 Hydrogeological parameters affecting electrical resistivity measurements.

Within a saturated material the electrical resistivity is a function of the porosity, the electrical resistivity of the saturating fluid, the resistivity of the solid rock or soil, the surface conductance of the rock or soil and the tortuousity of the fluid and electrical path (Urish 1981). It follows then that the conduction of electrical current through this material will be governed by two main mechanisms;

(1) Pore water conduction: For fluids of high salinity (low electrical resistivity) saturating clay free material, it is typically assumed that all of the electricity is conducted by the fluid through the pore space. The bulk resistivity of this material will then be a function of porewater, tortuousity, and effective porosity. A relation will exist between the total resistivity and the fluid resistivity, which will remain constant with varying fluid resistivity, namely (after Archie 1942);

$$F = \frac{p_t}{p_w} \qquad \text{Equation 3.5}$$

where $p_t$ = measured bulk resistivity

$p_w$ = fluid resistivity

F = formation factor.

This empirically defined relation has also been expressed as;

$$F = a \times \phi^{-m} \qquad \text{Equation 3.6}$$

where $\phi$ is porosity

and a & m are constants representative of intrinsic properties of the grain matrix. For unconsolidated fresh water sands 'a' is about 1.0 and 'm' is about 1.3 (Frohlich 1974)

(2) Matrix conduction: For fluids of relatively low salinity saturating unconsolidated sediment with a significant percentage of fine material, in particular clays, conduction involving pore water/matrix interactions will take place. This form of conduction is commonly termed matrix conduction (Worthington 1975, Urish 1981) and is brought about by interaction of the solid matrix and the surrounding pore water creating an ion rich zone around grains which forms an easy path for electric current flow.

When matrix conduction is dominant, the relation between total resistivity and fluid resistivity will not remain constant with varying fluid resistivity and therefore any applicable relationships between electrical resistivity and porosity are not likely to exist (see section 3.3.9). Further, the relation F will not be an intrinsic formation factor but an apparent formation factor, $F_A$, which includes the effect of surface conductance and other intergranular porewater contributions, (Urish 1981).

The alluvial materials forming the Cheviot plains contain a significant percentage of fines, both as silt and clay in the matrix and as distinct layers within the aquifer. Conductivity analysis has also shown that the pore water in both plains areas is saline. It can then be assumed that higher resistivities indicate material with less fines, and possibly greater effective porosity, (Risk 1982).

3.3.6 Ambiguity in resistivity interpretation

The interpretation of a multilayer sounding curve generally is not unique, therefore any given electrical sounding can correspond to a variety of subsurface distributions of layer thickness and resistivity (Sharma 1982). It follows then that ambiguities can arise in which the number of layers is unclear.

Two of the most common ambiguities which occur in interpretation of sounding curves are classically explained by the principles of equivalence and suppression:

(1) Electrical equivalence: This occurs when changes in resistivity and thickness of an intermediary layer do not produce any noticeable changes in the form of the sounding curve. Consider the case of two sounding curves each producing three layer sections. In each three layer section the first layer resistivity ($p_1$) is less than the second, and the second layer resistivity ($p_2$) is greater than the third ($p_3$), otherwise known as the K type (U.S dept of Interior 1980). If $p_1$ in one curve equals $p_{1i}$ in the other, $p_3$ equals $p_{3i}$ and;

$$T = p_2 \times h_2 = T^i = p_{2i} \times h_{2i} \qquad \text{Equation 3.7}$$

then the sounding curves for both sections will be practically identical. Such sections may be called equivalent with respect to T (see Bhattacharya & Patra 1968).

The influence of electrical equivalence in the interpretation of sounding curves at sites in the Cheviot region is evident when one considers that 94% of the three layer cases were of the K type and of the four layer cases the respective layer relations ranged from HK to KQ, which is similar in form to the K type, (see Table 3.1).

Table 3.1 Relation of respective geoelectric layers to overlying and underlying layers - Mina and Spotswood

| Mina Sounding No. | Number of layers | Relation of layer resistivities ($\rho$) (ohm) | Type Curve |
|---|---|---|---|
| A1 | 3 | $\rho_1 < \rho_2 > \rho_1$ | K |
| A2 | 2 | $\rho_1 > \rho_2$ | – |
| A3 | 3 | $\rho_1 < \rho_2 > \rho_3$ | K |
| A4 | 3 | $\rho_1 > \rho_2 > \rho_3$ | Q |
| A5 | 3 | $\rho_1 < \rho_2 > \rho_1$ | K |
| A6 | 3 | $\rho_1 < \rho_2 > \rho_1$ | K |
| A7 | 4 | $\rho_1 > \rho_2 > \rho_3 > \rho_4$ | QQ |
| A8 | 4 | $\rho_1 > \rho_2 < \rho_3 > \rho_4$ | HK |
| A9 | 3 | $\rho_1 < \rho_2 > \rho_3$ | K |
| A10 | 3 | $\rho_1 < \rho_2 > \rho_3$ | K |
| A11 | 3 | $\rho_1 < \rho_2 > \rho_3$ | K |
| Spotswood | | | |
| C1 | 4 | $\rho_1 < \rho_2 > \rho_3 > \rho_4$ | KQ |
| C2 | 3 | $\rho_1 < \rho_2 > \rho_3$ | K |
| C3 | 4 | $\rho_1 > \rho_2 < \rho_3 > \rho_4$ | HK |
| C4 | 3 | $\rho_1 < \rho_2 > \rho_3$ | HK |
| D1 | 4 | $\rho_1 < \rho_2 < \rho_3 > \rho_4$ | AK |
| D2 | 3 | $\rho_1 < \rho_2 > \rho_3$ | K |
| D3 | 3 | $\rho_1 < \rho_2 > \rho_3$ | K |
| D4 | 3 | $\rho_1 < \rho_2 > \rho_3$ | K |
| D5 | 4 | $\rho_1 > \rho_2 < \rho_3 > \rho_4$ | HK |

(2) The Principle of Suppression: This principle applies for Sounding curves which are interpreted as three layer sections. If the middle layer ($p_2$) is of insufficient thickness and/or resistivity relative to thickness and resistivity of layers above ($p_1$) and below ($p_3$) then it will not influence the sounding curve; its presence will be suppressed. Therefore a layer must be of sufficient relative thickness, namely the ratio of the layer's thickness to its depth of burial, before it will influence a sounding curve (Sharma 1982). Consequently the smaller the relative thickness of a given layer the the chance that its presence will be suppressed.

3.3.7. A special aspect of interpretation

Flathe (1976), illustrated the limitations inherent in electrical sounding interpretation by introducing a case study in which for the one set of data anything from four to twelve different models could be interpreted, each model representing a normal geological sequence. Naturally enough 'multi optional' model interpretations can quickly become confusing. Although there is no unique solution, methods introduced originally by Flathe (1976) and expanded upon more recently by Dorn (1985) assist in eliminating some of the confusion.

Firstly it must be recognized that any given interpretation contains two levels of information. The first produces a model based only on the sounding curves themselves and provides information on the general structure of the area immediately beneath the sounding site. A second, more detailed level of information can be derived by the introduction of external information such as borehole lithologic logs and previously published maps and reports, in effect a geologic model . Only then can information on the fine structure of the sounding be obtained.

3.3.8 Results of the Cheviot Plains soundings

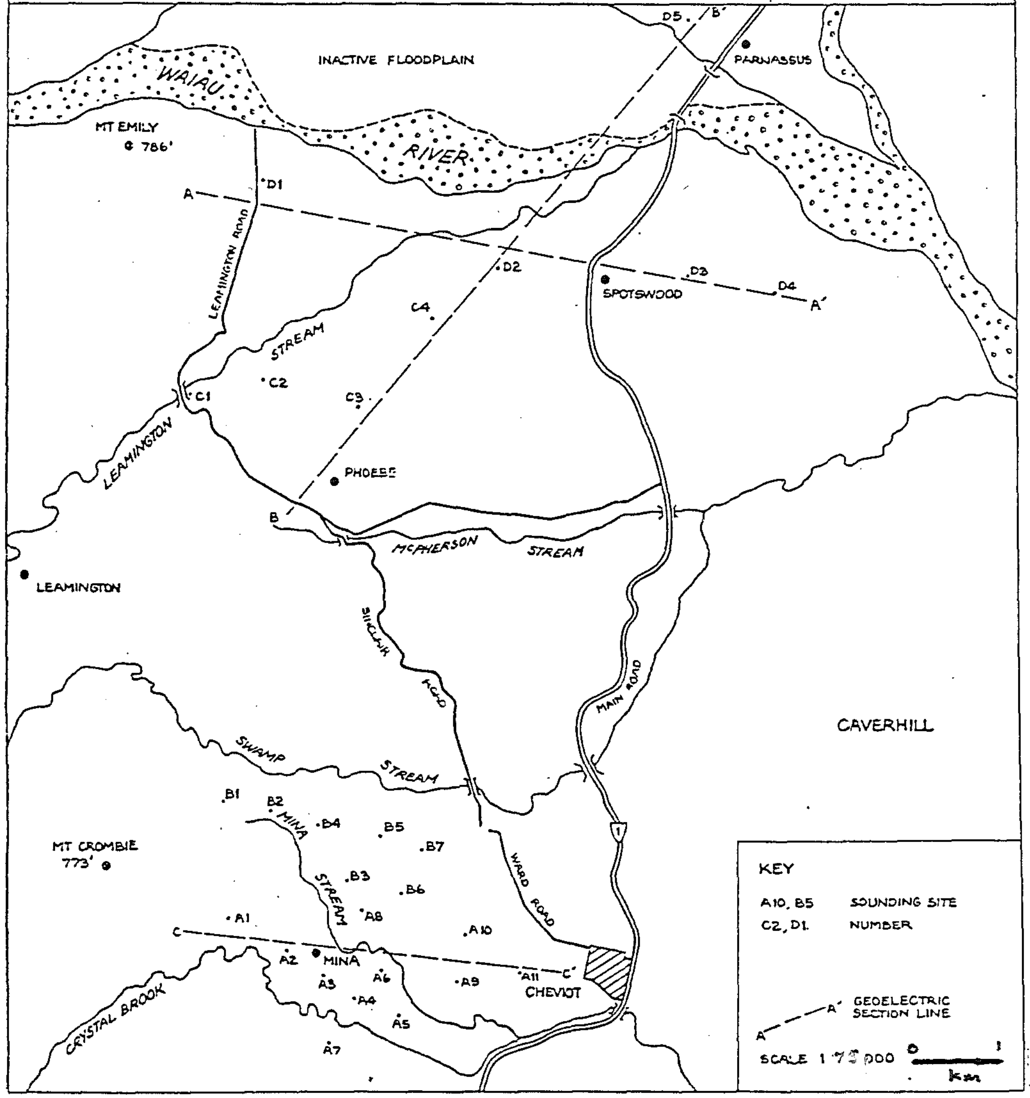
Of the twenty eight soundings carried out in the Cheviot region, eighteen were carried out across the Mina plains and a further ten were carried out across the Spotswood plains (Fig 3.2). All soundings lie near to four broad traverse lines A, B, C & D on Fig 3.2. and have been labelled;

A1 - A11, B1 - B7, C1 - C4 and D1 - D5.

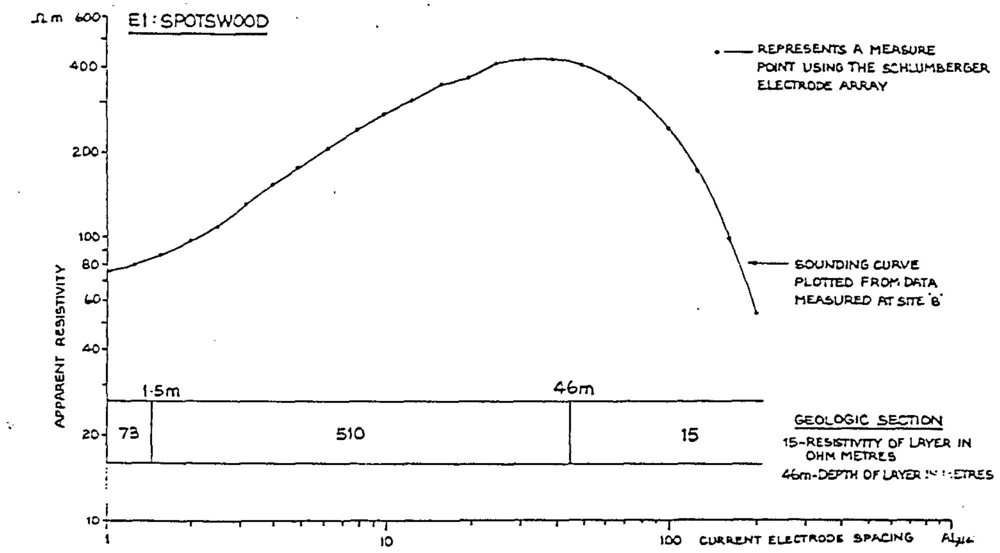
Soundings at sites A2, A8, A11, C2 and D1 were at first abandoned due to wet weather which is not conducive to good electrical resistivity

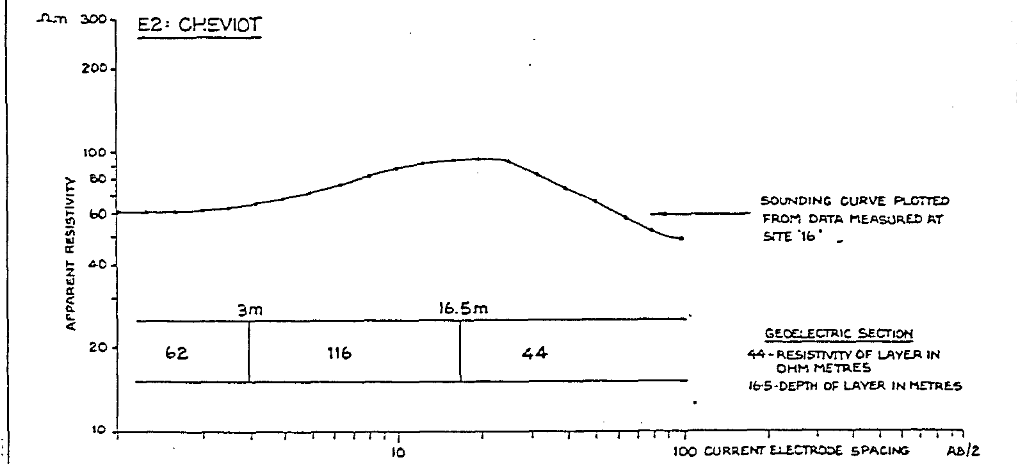
Fig 3.2. Location diagram of the 27 electrical resistivity soundings carried out on the Mina and Spotswood Plains. A sounding curve from each area with interpreted model is also presented

## LOCATION DIAGRAM




## PRESENTATION OF SOUNDING CURVE AND INTERPRETED MODEL



results, but were later repeated.

Interpreted resistivity models derived from the observed data are plotted as geo-electric sections (Table 3.2), showing the most prefered distribution of apparent resistivity below traverse lines A, B, C & D, and is consistent with the measured data listed in Appendix 3.2.

Interpreted resistivities from soundings in the Mina and Spotswood plains reveal three main geoelectric units. Four units were detected at a number of sites, where a surface clay layer is overlain by discontinuous very thin gravel less than one metre thick. This illustrates the sensitivity of the Direct Current electrical resistivity method to layers at shallow depths. Such details are however not detectable at depth.

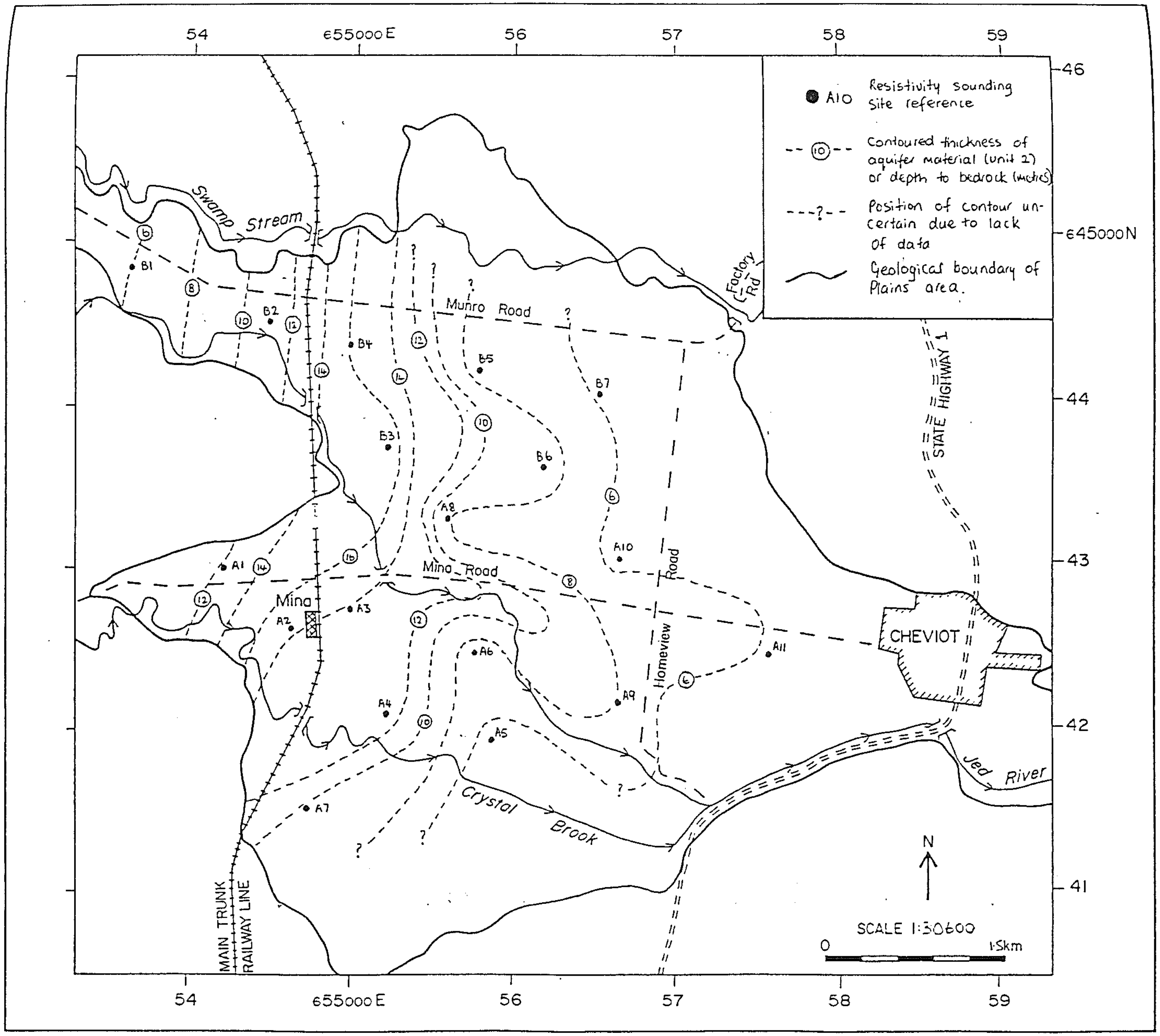
The first major geo-electric unit is areally extensive being common to both the Mina and Spotswood area. The unit is homogenous, with little variation in average layer resistivity and thickness 47 ohm-m and 4 meters for the Mina area, and 40ohm-m and 3 meters for the Spotswood area. The low resistivity values for this unit indicate a massive unit consisting of silt and clay. Directly underlying the 40 ohm-m layer is a unit which unlike the first varies significantly in resistivity and thickness in the Spotswood and Mina plains and consequently soundings carried out in both areas are discussed separately. In both areas this second unit represents the aquifer section, and the third unit represents bedrock.

(1) Mina plain: Here the second geoelectric unit has an average resistivity value of 140 ohm-m and thickness of 10 metres. The thickness of this unit is relatively uniform over the western sector of the Mina plains (Fig 3.3), ranging from a maximum of 14 metres at sites A2-3 to 10 metres at sites A5-6-7. The unit appears to thin towards the east, based on soundings A11 and A10, with unit thickness of 8 and 5 metres respectively.

Average resistivity values for this second unit do not vary significantly over the Mina plain area although the contoured map of apparent resistivity does show a general trend similar to that of the average thickness contour map, namely higher values in the western section of the area (Fig 3.4). The average resistivity for this unit at site A9 of 66

Fig 3.3. Contoured thickness of aquifer material (unit 2) interpreted from geoelectric sections, contour values also show depths to bedrock-Mina Plains

Fig 3.4. Contoured resistivity values (ohm-m) of aquifer material (unit 2) interpreted from geoelectric sections-Mina Plains



54
€55000E
56
57
58
59
46
€45000N
44
43
42
41
A10 Resistivity sounding site reference
(10) Contoured thickness of aquifer material (unit 2) or depth to bedrock (metres)
? Position of contour uncertain due to lack of data
Geological boundary of Plains area.
Swamp Stream
Munro Road
Factory Rd
STATE HIGHWAY 1
Mina Road
Mina
Homeview Road
CHEVIOT
Crystal Brook
Jed River
MAIN TRUNK RAILWAY LINE
N
SCALE 1:30600
0
1·5km
655000E


FIG 3.3

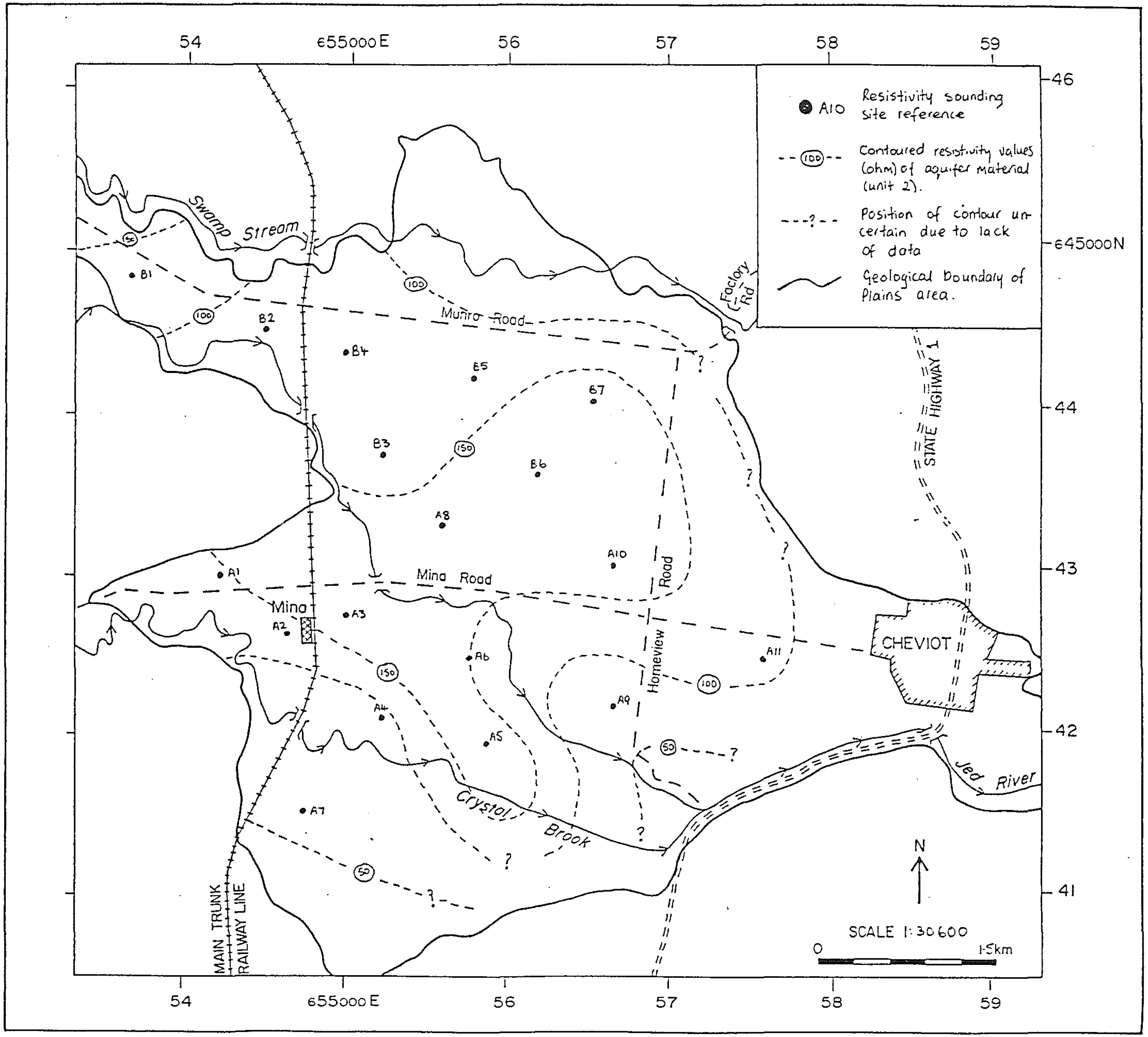

A10 Resistivity sounding site reference
(100) Contoured resistivity values (ohm) of aquifer material (unit 2).
--?-- Position of contour uncertain due to lack of data
Geological boundary of Plains area.
54
655000E
56
57
58
59
46
645000N
44
43
42
41
Swamp Stream
Munro Road
Mina Road
Mina
Horneview Road
Factory Rd
STATE HIGHWAY 1
CHEVIOT
Jed River
Crystal Brook
MAIN TRUNK RAILWAY LINE
B1
B2
B3
B4
B5
B6
B7
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
50
100
150
N
SCALE 1:30600
0
1·5km

FIG 3.4

Table 3.2 Summary of layer resistivities and thickness - Spotswood Plains

| Sounding Number | Number of Inferred Layers | Inferred Resistivity of 1st layer (ohm) | Thickness (m) | Inferred Resistivity of 2nd layer (ohm) | Thickness (m) | Inferred Resisitivty of 3rd layer (ohm) | Thickness (m) | Inferred Resistivity of 4th layer (ohm) |
|---|---|---|---|---|---|---|---|---|
| C1 | 4 | 179 | <1 | 466 | 2 | 90 | 10 | 20 |
| C2 | 3 | 70 | 7 | 433 | 14 | 28 | | |
| C3 | 4 | 513 | 1 | 118 | 11 | 328 | 14 | 36 |
| C4 | 3 | 26 | 2 | 346 | 41 | 23 | | |
| D1 | 4 | 48 | <1 | 155 | 8 | 968 | 28 | 48 |
| D2 | 3 | 73 | 2 | 511 | 45 | 15 | | |
| D3 | 3 | 13 | 2 | 362 | 29 | 36 | | |
| D4 | 3 | 34 | 6 | 281 | 31 | 35 | | |
| D5 | 4 | 59 | <1 | 19 | 10 | 167 | 78 | 26 |
| Average Values | | 346 | <1 | 40 | 3 | 422 | 32 | 31 |

Summary of layer resistivities and thickness - Mina Plains

| Sounding Number | Number of Inferred Layers | Inferred Resistivity of 1st layer (ohm) | Thickness (m) | Inferred Resistivity of 2nd layer (ohm) | Thickness (m) | Inferred Resistivity of 3rd layer (ohm) | Thickness (m) | Inferred Resistivity of 4th layer (ohm) |
|---|---|---|---|---|---|---|---|---|
| A1 | 3 | 74 | 5 | 153 | 12 | 16 | | |
| A2 | 2 | 146 | 14 | 30 | | | | |
| A3 | 3 | 99 | 1 | 157 | 14 | 31 | | |
| A4 | 3 | 1032 | 3 | 99 | 13 | 30 | | |
| A5 | 3 | 30 | 5 | 217 | 10 | 27 | | |
| A6 | 3 | 24 | 4 | 116 | 10 | 23 | | |
| A7 | 4 | 460 | <1 | 128 | 3 | 68 | 10 | 11 |
| A8 | 4 | 170 | <1 | 55 | 7 | 177 | 8 | 21 |
| A9 | 3 | 33 | 4 | 66 | 13 | 11 | | |
| A10 | 3 | 20 | 8 | 163 | 5 | 7 | | |
| A11 | 3 | 10 | 1 | 113 | 8 | 9 | | |
| B1 | 3 | 43 | 3 | 96 | 7 | 22 | | |
| B2 | 3 | 70 | 2 | 123 | 11 | 30 | | |
| B3 | 2 | 135 | 17 | 33 | | | | |
| B4 | 4 | 138 | 2 | 842 | 1 | 130 | 16 | 39 |
| B5 | 4 | 147 | <1 | 46 | 7 | 132 | 7 | 12 |
| B6 | 4 | 175 | <1 | 51 | 8 | 195 | 9 | 16 |
| B7 | 3 | 57 | 5 | 170 | 6 | 32 | | |

ohm, is of sufficient variance from the average value for the unit of 140 ohms, and could represent a local area of predominantly fine material associated with overbank deposits or point bar deposition. At site A7 a lower average value for the unit of 68 ohm-m, also indicates a material of predominantly fine material.

(2) Spotswood plain: For the Spotswood plain the second geo-electric unit has an average resistivity of 422 ohm-m and thickness of 27 metres which differs markedly with the equivalent geo-electric unit of Mina Plain indicating that the aquifer material for Spotswood is considerably thicker, coarser grained, and contains less fines (including clays). Unlike Mina, not all of the soundings in Spotswood were carried out on the same aggradational surface. Average unit resistivities for soundings carried out on the older remnant terrace surfaces namely C3-4 (328 & 346 ohm-m respectively) did not vary significantly with those attained from soundings carried out on the younger terrace surfaces, C2, D2-3-4 (433, 453, 362 & 281 ohm-m).

The average thickness of the second geo-electric unit does appear to vary in a northerly direction ranging from 14 metres at the most southerly site C3 located on the older terrace surface near Phoebe, to 48 metres at site D2 just 300 metres from the active floodplain of the Waiau river to 89 metres at the most northern site D5 situated on the active floodplain across the Waiau river near Parnassus (Fig 3.5).

The third geo-electric unit detected at all sites in both the Mina and Spotswood areas, differs markedly in average resistivity to the overlying second geo-electric unit. (note: In a number of soundings the AB/2 distance (current electrode spacing), was restricted due to the presence of roads, electric fences or livestock and consequently although the third unit was detected it was not fully electrically penetrated, especially in Spotswood surveys where the AB/2 often exceeded 120 metres. Therefore for several of the soundings the third units' resistivity was fixed at a value known to be accurate from other soundings which had fully penetrated the unit.)

In Mina area this third unit has an average resistivity value of 22 ohm-m which is a typical value of massive silts and clays, (ranging from 7 ohm-m at A10 to 41 ohm-m at B4) at an average depth of 10 metres.

Depth to bedrock contours relative to mean sea level, constructed from geo-electric data over the majority of the plains area at Mina, indicates the bedrock profile is uniform and gently dipping in a south easterly direction, for example at sounding sites A11, A10 and B6 are 51, 50 and 53 metres respectively (Fig 3.6). The depth to bedrock value at site A9 of 45 metres indicates a depression within the bedrock, perhaps associated with ancient stream channel, when compared to the depth to bedrock values either side of A9, namely 58 metres at A5 and 51 metres at A11. Interpretation based on one sounding, combined with the relative errors in depth parameters inherent in the technique render any further speculation of little value.

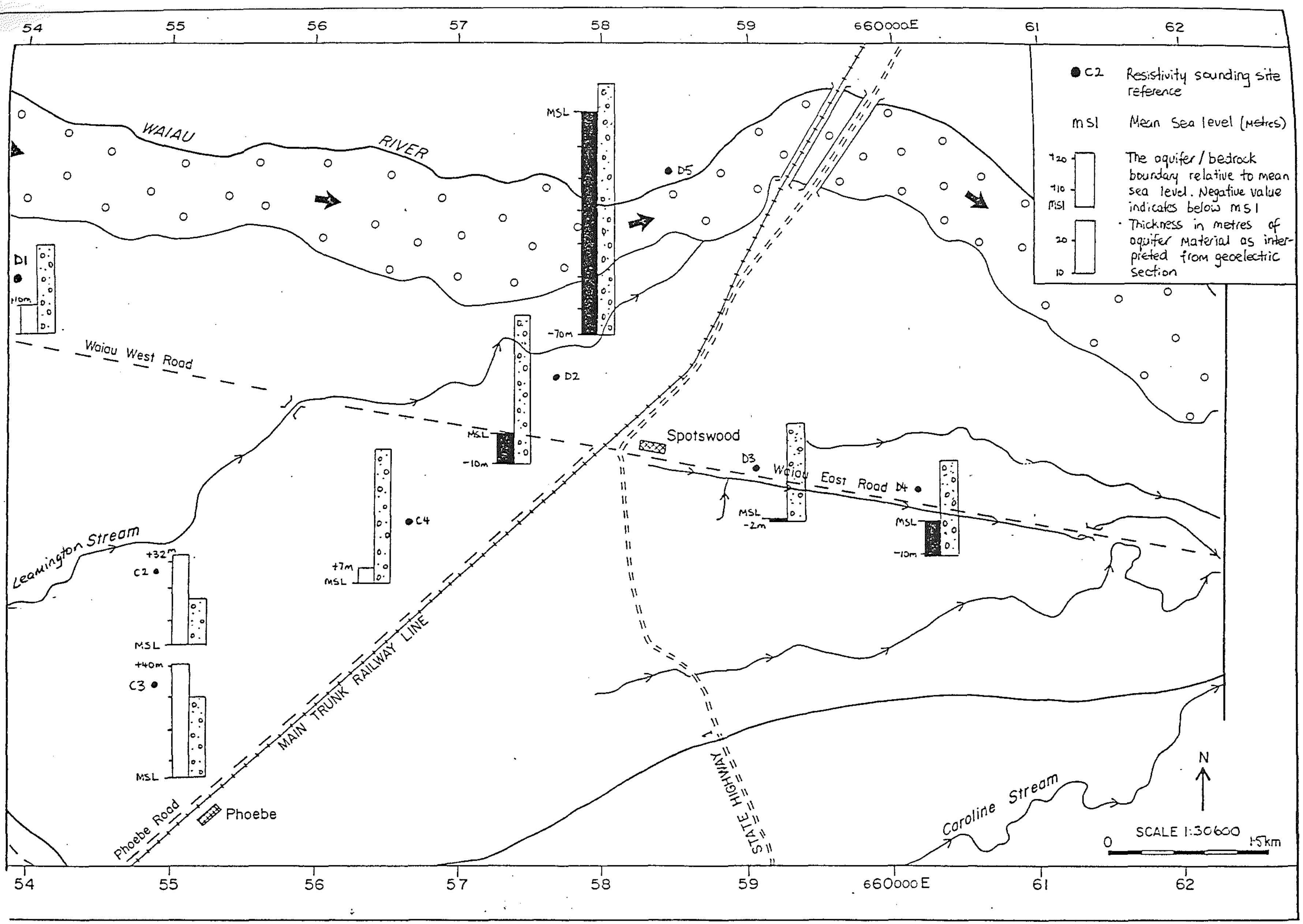
At Spotswood the third geo-electric unit (bedrock) has an average resistivity of 31 ohm-m (ranging from 20 ohms at C1 & D2 to 48 ohm-m at D1) occurring at an average depth of 33 metres. As the soundings were conducted over several aggradational surfaces, the only value of the average depth figure is in its comparison to the average value attained in Mina. The depth to bedrock map (Fig 3.5) shows clearly how the bedrock dips in a northerly direction towards Parnassus. The depth to bedrock range from site C3 of 33 metres to D2 of -9 metres and to D5 of -69 metres shows how the bedrock dips in a northerly direction from Phoebe to Parnassus at a gradient of about 1m horizontal : 0.042 metre vertical, and in a west-east direction from 9 metre at D1 to -11 metre at D4 (a gradient of about 1m horizontal to 0.007 metre vertical).

3.3.9 Correlation with bore material description logs

Several of the twenty soundings in the Cheviot region were carried out near bores where material descriptions are available. The degree of correlation between interpreted geoelectric sections (see section 3.3.7) and material descriptions is important to allow comparison of physical parameters. In the following discussion reference is made to layers of low and high (or higher) resistivity; the low resistivity layers are interpreted as silt or clay layers, and the high resistivity layers indicate an increase in particle size ranging from sand to very coarse gravel. The material descriptions referred to in this section have been summarised, detailed descriptions are given in Appendix 2.2 and 2.3.

Fig 3.5. Average thickness of aquifer material (unit 2) and depth to bedrock relative to mean sea level-Spotswood Plains

Fig 3.6. Contoured depths to bedrock relative to mean sea level in metres-Mina Plains



54
55
56
57
58
59
660000E
61
62
C2 Resistivity sounding site reference
msl Mean Sea level (metres)
The aquifer / bedrock boundary relative to mean sea level. Negative value indicates below msl
Thickness in metres of aquifer material as interpreted from geoelectric section
WAIAU RIVER
D1
D2
D3
D4
D5
C2
C3
C4
MSL
-70m
-10m
-2m
+32m
+40m
+7m
Waiau West Road
Waiau East Road
Spotswood
Leamington Stream
MAIN TRUNK RAILWAY LINE
STATE HIGHWAY 1
Phoebe Road
Phoebe
Caroline Stream
N
SCALE 1:30600
0
1.5km


Fig 3.5

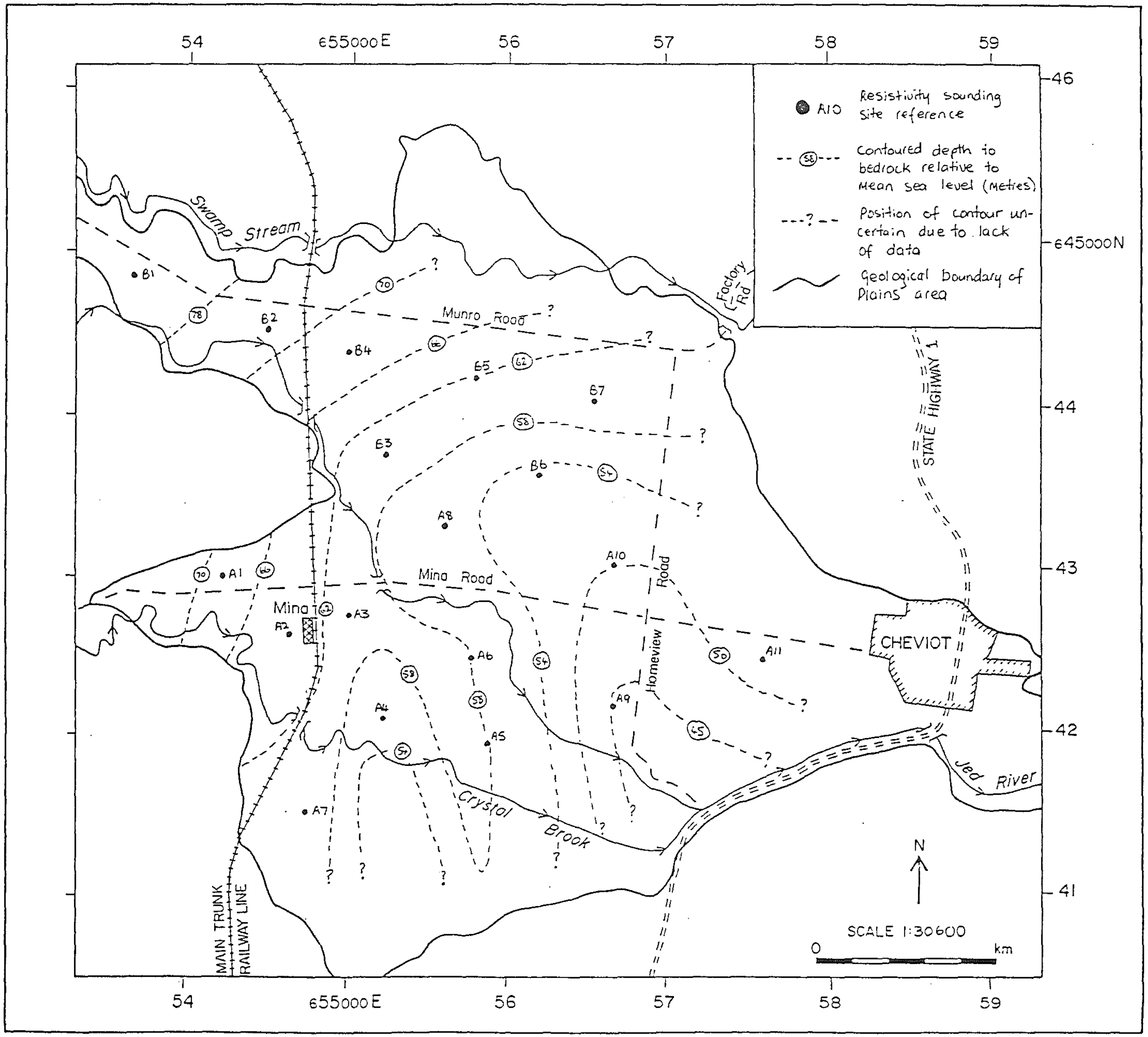

Resistivity sounding site reference
A10
Contoured depth to bedrock relative to Mean sea level (metres)
Position of contour uncertain due to lack of data
Geological boundary of Plains area
54
655000E
56
57
58
59
46
645000N
44
43
42
41
Swamp Stream
Munro Road
Factory Rd
Mina Road
Homeview Road
STATE HIGHWAY 1
Mina
CHEVIOT
Crystal Brook
Jed River
MAIN TRUNK RAILWAY LINE
B1
B2
B3
B4
B5
B6
B7
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
78
70
66
62
58
54
50
45
N
SCALE 1:30600
0
km

FIG 3.6

(1) The Mina Plain

On the Mina plain, one sounding A10 was conducted near bores where reliable lithologic logs are available, namely bore reference numbers 48, 17 and 19. Each material description identifies at least four or five layers. The stratigraphy is comprised of a top layer of clay and silt, a middle layer comprising two clayey gravel units separated by a clay layer, and a lower sequence of fine silts and muds. In the geoelectric section (A10) only three units are identified, reflecting the simplification of the section obtained (Fig 3.2). It was not possible to identify the clay layer interbedded within second layer, the clayey gravel unit described in nearby material descriptions. However, thickness of the respective layers and depths to the bottom layer representing bedrock generally were accurate within 20 to 30%. For example the depth to bedrock logged in bore 19 is 16.1 meters whereas the depth to bedrock given by the nearest sounding A10, is 13.7 meters.

In August 1987 three investigative holes (reference numbers 176, 177 and 74) were drilled on the Mina plains at localities where resistivity soundings had been already conducted, this provided an opportunity to compare directly the accuracy of the geoelectric sections obtained to information from drilling. The material descriptions from bores 176, 177 are similar to those from bores 19, 48 and 17, namely a sequence of surface clays, intermediary clayey gravels and a clay layer overlyin a section of silts and clays (bedrock). The major difference between descriptions of bores 176, 177, 48, 17 and 19 is the interbedded clayey gravel section in the latter is significantly better sorted. The geoelectric soundings A2, 3, 4, and B3 failed to identify the clay layer interbedded within the clayey gravel section described in bores 176 and 177, but did show the general nature and structure of the layers.

The depths to bedrock given by the electric soundings which had previously been carried out near bore reference numbers 176 (A2, 3 & 4) ranged from 11.3 to 16.1 meters which compared favourably to the depth determined by drilling of 15.3 meters. Electric sounding B 3, which had been carried out near bore 177 suggested that bedrock was at a depth of 17 meters. (this was an influencing factor in the decision to drill at this location). Consequent drilling showed that bedrock is at 11.3 metres, within 33 % of the depth of 17 determined by sounding B 3, which again is satisfactory. Bore 78 was drilled to only 4.5 meters, and failed to reach bedrock. The subsurface geology was much the same as described at other bores in the area, namely 2 metres of silts and clays, underlain by a gravel section 1 to 2 metres thick. This gravel differs from the gravel layers in bores 176 and 177 with better sorting and a reduced fines concentration. Underlying this gravel layer are clays of undetermined thickness as drilling did not continue to beyond 4.5 metres in depth.

The geoelectric section for sounding A11, carried out 50 meters from the drillsite of bore 178 showed there to be three layers consisting of a low resistive surface layer, (10 ohm-m) an intermediate higher resistivity layer (113 ohm-m) and an underlying low resistive layer (9 ohm-m) at 9 meters. As the intermediary layer had an average resistivity less than that of bores 176 and 177, it is considered to have a higher concentration of fines throughout the section. The sounding had failed to detect the relatively thin very well sorted gravel layer at 2.5 meters because its relative thickness is not great enough, illustrating the limitations of resistivity interpretation.

(2) The Spotswood Plains

In the Spotswood plains three soundings were carried out near boreholes where material descriptions are available, namely D1 (bore reference 56) and D3 & 4 (bore reference 19, Fig 3.2).

Geoelectric section D1 correlated well with the material description of bore 56. D1 showed there to be a thin surface low resistive layer (clays), a second layer of higher resistivity, a third layer of very high resistivity (gravels) and a fourth layer of low resistivity (bedrock) at 37 ohm-m, it did not however detect the water table which was known to be at approximately 6 metres, and this may be attributable to partial saturation of the material above the water table at the time of survey. Bore 56 log showed there to be a 2.5 metre surface clay layer overlying moderately well sorted gravels, which continued until drilling stopped at 17 meters. As the borehole did not reach bedrock no correlation of depth to bedrock given by the sounding D1 was possible.

Geoelectric section D3 & D4 showed similar results, namely a low resistive layer (13-34 ohm-m) of 2-6 meters, a second higher resistive middle section (281-362 ohm-m) of 29-31 meters, overlying a low resistive lower section (35-36 ohm-m). The material description from bore 19 indicates a 1.0 metre clay layer at a depth of 8.0 metres within the gravel unit again this is not indicated by the electric soundings again because of the ambiguity associated with electrical suppression. Bore 19 reached only to a depth of 12 metres, so a check on the accuracy of the depth to bedrock parameter given by geoelectric section D3 & D4 was not possible.

The results indicate clearly the limitations of initial two, three and four layer interpretations based on electrical averaging when compared with available bore material descriptions. Descriptions typically revealed three or more layers in the aquifer while sounding curves typically showed only one. Basically the inherent ambiguities discussed in section 3.3.6, namely resistivity contrasts and 'effective' relative thickness (Flathe 1976; Keller & Frischknecht 1966) within the aquifer are too small to be distinguishable. Suppression also occurred because relatively thin confining clay layers are overlain and underlain by highly resistive layers. So although it was generally possible to fit the geoelectric to the geologic section, layers within the aquifer section could not have been determined from the sounding curve alone.

3.3.10 Conductivity of water samples

The specific electrical conductance (conductivity) of water is defined as the ability of a cube of the substance, with side measuring one centimetre to conduct electrical current (Matthess 1982), and is measured in units of seimens. An independent determination of the conductivity of groundwater is important in an investigation which employs the electrical resistivity method because of its influence on the measured bulk resistivity.

As part of this study twenty samples were collected from suitable wells in July 1987 throughout the Cheviot region. A trailer mounted pump was required to collect a sample from the majority of wells although several household supply taps also provided adequate samples. Five of the twenty samples were analyzed in the field with the N.C.C.B's hand held Radiometer CDM 2E, for conductivity, acidity and temperature. The remaining fifteen were taken and analyzed in the North Canterbury Catchment Boards chemistry laboratory for chemical analyses (see Chapter 4).

A summary of conductivity results are included in table 4.4, Chapter 4. Within the Spotswood plains area sampling sites located near to the Waiau river had consistently low conductivity values, typically less than 20 ms/m (sample sites S2, S3, S6, Table 4.4). The further the sampling site is located from this major recharge source the more conductive the groundwater becomes, typically with values between 30 and 50 ms/m (sample sites S1 and S5), indicating that pore water has increased dissolved salt content.

The relatively low conductivity values attained for groundwater on the plains area immediately adjacent to the Waiau river coupled with the fact that appreciable quantities of fine deposits (including clay minerals) are present in the material indicates electrolytic conduction is influenced by conduction involving pore water-matrix interactions.

In comparison to the relatively low values recorded for groundwater on the Spotswood plains, conductivity values for groundwater in the Mina plains are consistently high, typically of the order of 70 to 110 ms/m, (sample sites M2, M3, M4, M5). At sample site in particular M4, a remarkably high conductivity value was recorded, namely 153 ms/m. These high values as well as results from water quality analysis (see Chapter 4) indicate external contamination possibly from a nearby septic tank or cattle yard at the site.

The high conductivity values attained for groundwater in the Mina plain indicates that electrolytic conduction through the free pore water is the dominant conduction mechanism. However, because of the high concentration of clay minerals in the material, conduction is also likely to involve pore water/matrix interactions.

3.3.11 The relationship between resistivity and porosity

(1) Formation factor (F)

In section 3.3.5 it was shown that if the bulk resistivity of a material was solely a function of porewater, tortuousity and effective porosity, a relation exists between the total resistivity and fluid resistivity which will remain constant with varying fluid resistivity, namely the formation factor. As in previous resistivity surveys conducted on unconsolidated material in the Canterbury region (Risk 1982, Broadbent 1985) it was initially hoped that such a relation would exist and areas of relatively permeable and impermeable material identified. However it has been shown that the unconsolidated materials at both Mina and Spotswood contain significant fractions of conductive fine material. This material provides additional conduction paths so that the bulk resistivity will not be proportional to fluid resistivity and the apparent formation factor will not be constant for a particular material.

As a check of the relative contributions of pore water and matrix conduction to the total conduction process in each plains area, a comparison was made of the bulk resistivities of the main aquifer with resistivities of water samples from wells close to the sounding sites, (Fig 3.7). Fig 3.7 shows the data points do not plot along a particular F line but show a broad scatter, indicating that matrix conduction has a dominant effect on the conduction process, and that the degree of matrix conduction varies for both areas.

(2) Alternatives to F

Based on the literature to date three alternatives exist which could prove useful methods of identifying relative permeability within the study area:

(i) Mendleson and Cohen (1982), derive a complex mathematical formulae in an attempt to estimate porosity from resistivity measurements when matrix conduction is known to be a dominant conduction mechanism. Interestingly one of the conclusions from his study was that Archies Law (section 3.3.5) is a special case where no matrix conduction takes place.

Mendleson's calculations were based on theoretical estimates of m, the cementation factor for sediments of varying particle sizes. Recent work with these formulae by Broadbent (pers comm 1987) has shown that reasonable estimates of porosity can be made. However the inherent errors involved in making theoretical estimates on material as diverse as unconsolidated alluvium lead to the conclusion that the only satisfactory way of attaining accurate values of m, is to collect core samples in the field and conduct relevant laboratory tests. Whether suitable core samples could be collected successfully from the unconsolidated deposits is doubtful, however it is an aspect on which further research is warranted. Unfortunately the application of Mendleson's equations requiring accurate estimates of m is beyond the scope of this study.

Fig 3.7. Inferred bulk resistivities of main aquifer (unit 2) plotted against resistivity of bore water for measurements on traverse lines (A, B, C, D). Solid lines represent different values of Formation Factor $F$ (adapted from Risk 1982)

GORMACK GRAPH PAPERS C101Y 19 cm x 28 cm in mm

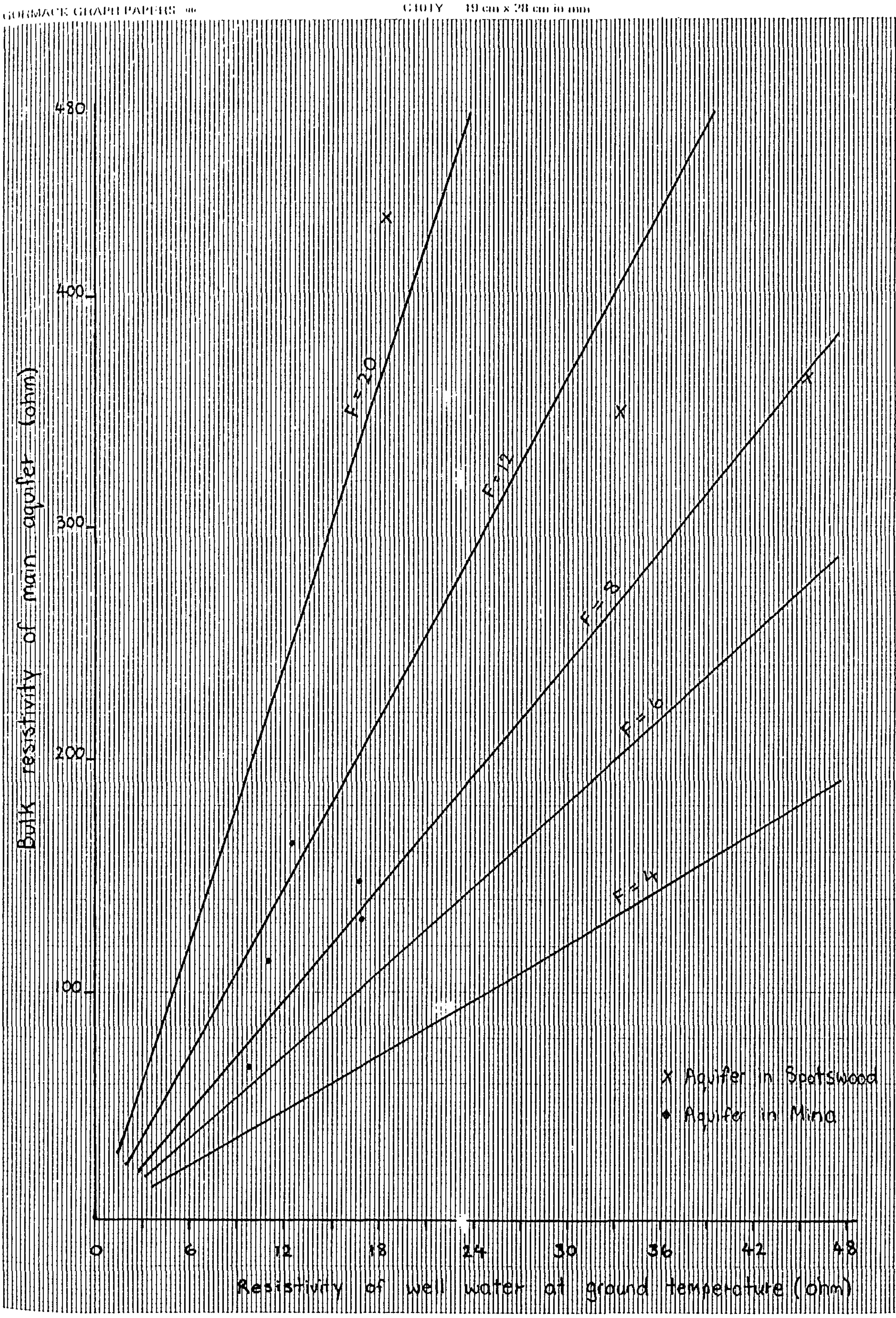



FIG 3·7

(ii) The dependence of correlations between formation factor and porosity on the depositional environment and constant water salinity have resulted in the suggestion of utilizing known relations between porosity and matrix resistivity (Huntley 1986). He showed there to be a direct relation between matrix resistivity and effective porosity based on earlier work by Patnode & Wyllie (1950) and others . To evaluate the effects of electrical conductance through other than the fluid Patnode & Wyllie (1950), Worthington (1977) and Urish (1981) have shown that

$$\frac{1}{R_t} = \frac{1}{R_w} + \frac{1}{R_g} + \frac{1}{R_m} \qquad \text{Equation 3.8}$$

where $R_t$ is the total measured resistivity

$R_w$ is the resistance of fluid in pores

$R_g$ is the resistance of grains or rock

and $R_m$ is the resistance along surface of grains or rock due to surface conductance effects, referred to as matrix conduction.

As the magnitude of the electrical resistance of the rock or grains is significantly greater than that of the fluid and that due to surface conduction, even for low-salinity fluids, and applying the relations between electrical resistance and resistivity results in;

$$\frac{1}{p_t} = \frac{1}{(p_w \times F)} + \frac{1}{p_m} \qquad \text{Equation 3.9}$$

where $p_{t,w}$ is as defined above

$F$ = intrinsic formation factor

$p_m$= matrix resistivity (due to surface conductance)

Thus if $p_t/p_w = F_a$

where $F_a$= apparent (measured) formation factor then

$$\frac{1}{F_a} = \frac{1}{F} + \frac{p_w}{p_m} \qquad \text{Equation 3.10}$$

Therefore from a linear plot of $1/F_A$ to $p_w$ an estimate can be made of the intrinsic formation factor, $F_i$ and the matrix resistivity $p_m$, where Fi is the intercept and $p_m$ is the slope of the line. Such a plot was attempted (Fig 3.8) the results are inconclusive. For example the

Fig 3.8. Plot of inverse apparent Formation Factor versus resistivity of groundwater-Mina and Spotswood Plains areas (adapted from Huntley 1986)

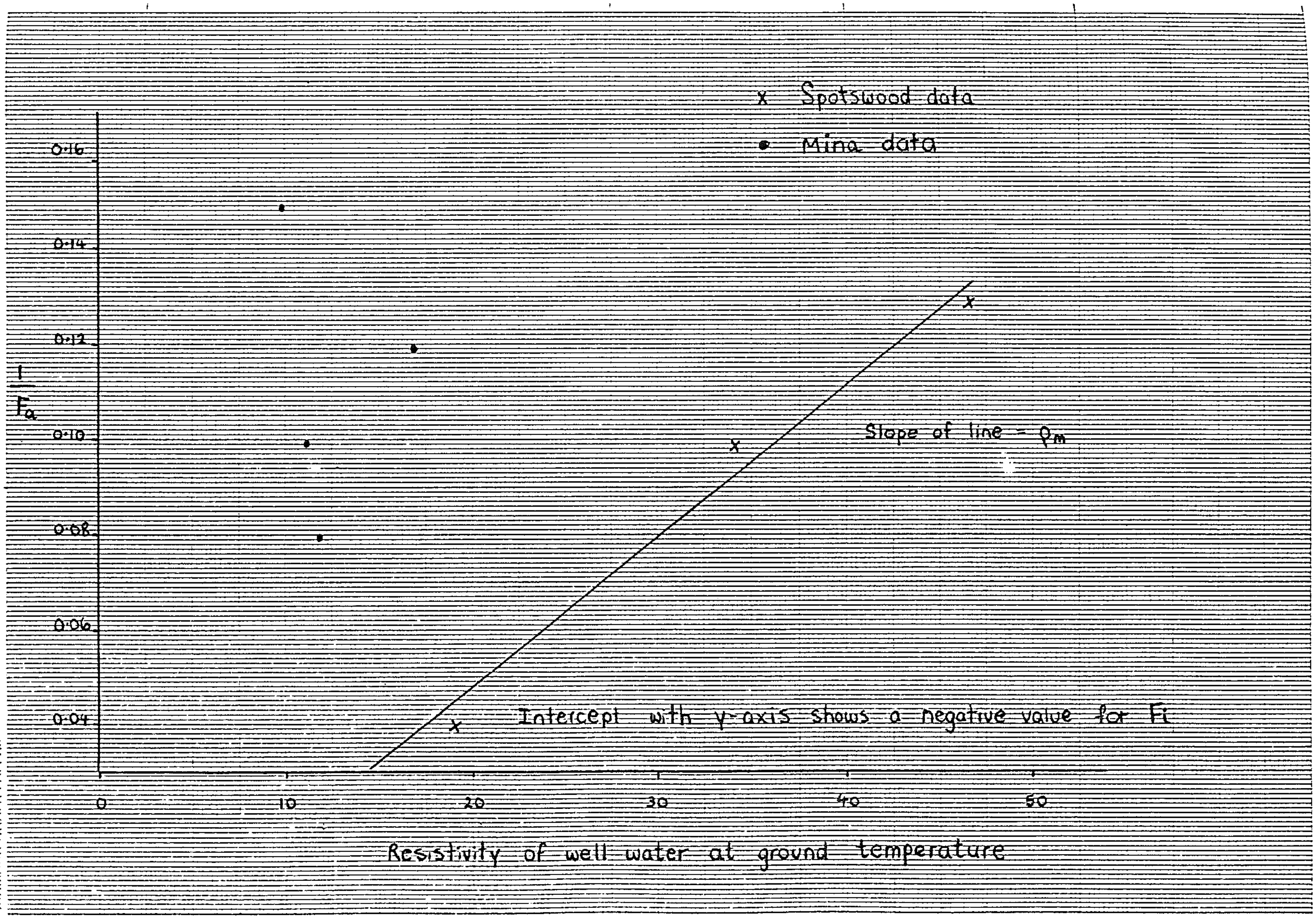

x Spotswood data
• Mina data
0·16
0·14
0·12
0·10
0·08
0·06
0·04
$\frac{1}{F_a}$
0
10
20
30
40
50
Slope of line = $\rho_m$
Intercept with y-axis shows a negative value for Fi
Resistivity of well water at ground temperature

FIG 3.8

data points plotted from sites in Mina had a broad scatter and a best fit line could not be drawn. The plotted data points from sites in Spotswood did plot on a straight line but its intercept on the $1/F_a$ axis provided a negative value for the Fi which is clearly erroneous. If the degree of matrix conduction was constant within the Spotswood and Mina gravels a reasonably straight line would be expected on the $1/F^a$ vs $p_w$ plot, even allowing for reasonable scatter due to operator error. The wide scatter from data obtained at Mina and the erronous straight line plot of the Spotswood data indicates that the degree of influence of matrix conduction on the conduction mechanism in these areas is not constant.

As in section 3.3.10, (1), it seems the only reliable way of estimating matrix resistivity when matrix conduction is dominant is to obtain a core sample and carry out relevant laboratory tests, which would be a extremely difficult to achieve.

(iii) An alternative to a comprehensive laboratory programme based on as yet unproven techniques is that suggested by Risk (1982) in which high measured bulk resistivity values are used to identify areas of greater permeability. Certainly higher resistivities were attained for gravel sections in Spotswood than in Mina where it has been proved through pump tests that the gravels are considerably more permeable.

## 3.4 Nuclear Borehole Logging

As part of this study a suite of three Nuclear logs (natural gamma, gamma-gamma and neutron) and a caliper log were run on four boreholes in the Cheviot region, two in each respective study area. The nuclear logs were run in an attempt to obtain quantitative estimates of porosity and density for the various materials logged during drilling. A comparison could then be made between the excellent water producing materials in Spotswood to the relatively poor producing materials in Mina.

### 3.4.1 Background

Radiation logs are used to measure the natural radioactivity of the formations adjacent to the borehole and their response to bombardment by neutrons or gamma rays. The radiation suite ran at the Mina and Spotswood boreholes consisted of;

(1) Natural gamma logging: Gamma logs provide a continuous measurement of the natural radioactivity of formations intersected by the borehole. In most sedimentary rocks the log reflects the clay content of formations caused by radioactive elements' tendency to concentrate in rock

containing clay minerals. In general, natural gamma count rates will increase with increasing clay content.

(2) Gamma-gamma logging: The gamma-gamma or density log responds to the gamma rays emitted by a source within the probe and backscattered by the surrounding formations. The back scattered gamma rays counted by a detector are inversely proportional to the bulk density of the formation.

(3) Neutron logging: The neutron log responds to the amount of hydrogen in the formations surrounding the borehole. Below the water table the log may be used to estimate porosity providing the required calibration charts are available for the particular sized borehole. The neutron log has the advantage over the other radiation logs in that it is not affected appreciably by formation chemistry. In general an increase in the neutron count rate will indicate an increase in total porosity. However an increase in total porosity indicated by the neutron log does not necessarily indicate an increase in effective porosity or permeability but may from the natural gamma log indicate an increase in clay content. The more permeable zones are usually indicated by highest total porosities on the neutron log and lowest clay content from the natural gamma log.

3.4.2 Results.

Of the four boreholes logged in the Cheviot region only three are of similar bore, reference 19 in Spotswood and bores 176 and 177 in Mina. Each of these three boreholes are 150 millimetres in diameter, whereas the diameter of the other bore logged, bore 57 in Spotswood is 300 millimetres. Unfortunately suitable charts to correct for the difference in borehole diameter are not available, consequently the interpreted lithologic log from N33.57 can only be used to describe in a qualitative manner the material at that site, relative quantitative comparisons determined from calibration charts at the other sites are not possible.

Calibration charts for cased, water filled NX (150 millimetres) sized boreholes were attained from P.White (Ministry of Works & Development, Christchurch) which enabled quantitative analysis (density and porosity, Appendix 3.3) of the three respective 150 millimetres boreholes in Cheviot. Unfortunately density and porosity estimates could not be made in the screen sections of each hole because casing and screen diameters differ from 3.0 centimetres at bore 19 to 5.5 & 6.0 centimetres at the logged bores in Mina.

Results from the nuclear logs conducted at bore 19 in Spotswood showed two major materials (Fig 3.9). The first material is predominantly fine grained, ranging from sandy silt to silty clay occurring at the surface from 0-2.5 metres and again from 6.2-7.5 metres. The sandy silt has estimated densities of Each confining layer has estimated densities of approximately 1.15 $g/cc^3$ and relatively high porosities (upto 40%) reflecting the high silt and clay content. The second material consists of sandy and silty gravels with some clay, clearly indicated by low natural gamma count rates (85-91 counts/sec) corresponding higher densities ($1.32 g/cc^3$) and porosities from approximately 26-29%. The effective porosity appears to be quite uniform in the gravel material above 7.6 metres. However from 7.6-8.6 metres significant drops in natural gamma count rates (approximately 60 counts/sec), lower densities $1.02 g/cc^3$ and higher porosities (approximately 43%) indicate a layer with increased effective porosity.

Interpreted material logs from bores 176 and 177 on the Mina plains showed there to be an interbedded sequence of relatively thin (less than 1.0 metre) silty gravels and clay bound gravels occasionally with some sand, overlain by a silty clay layer two to three meters thick (Fig 3.10) The gravel section at bore 177 have consistently higher average porosities than at similar sections at bore 176, namely 31% and 24% respectively. As the gravels at 177also indicated lower clay contents it can be tentatively concluded that the gravels at Mina have relatively higher effective porosities than at 176. However, higher average natural gamma log count rates, higher densities and similar porosities indicate that the gravel sections at 176 and 177, have significantly lower effective porosities, and thus permeabilities, than similar sections at bore 19 in Spotswood.

Fig 3.9. Nuclear log compilation for boreholes 033.19 and N32.101-Spotswood Plains

FIG A: LOGS OF BOREHOLE 033 - 19

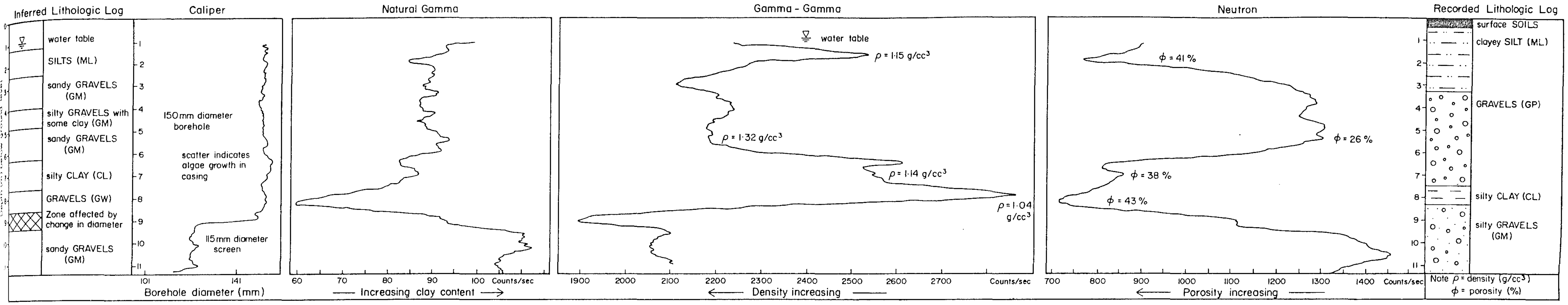
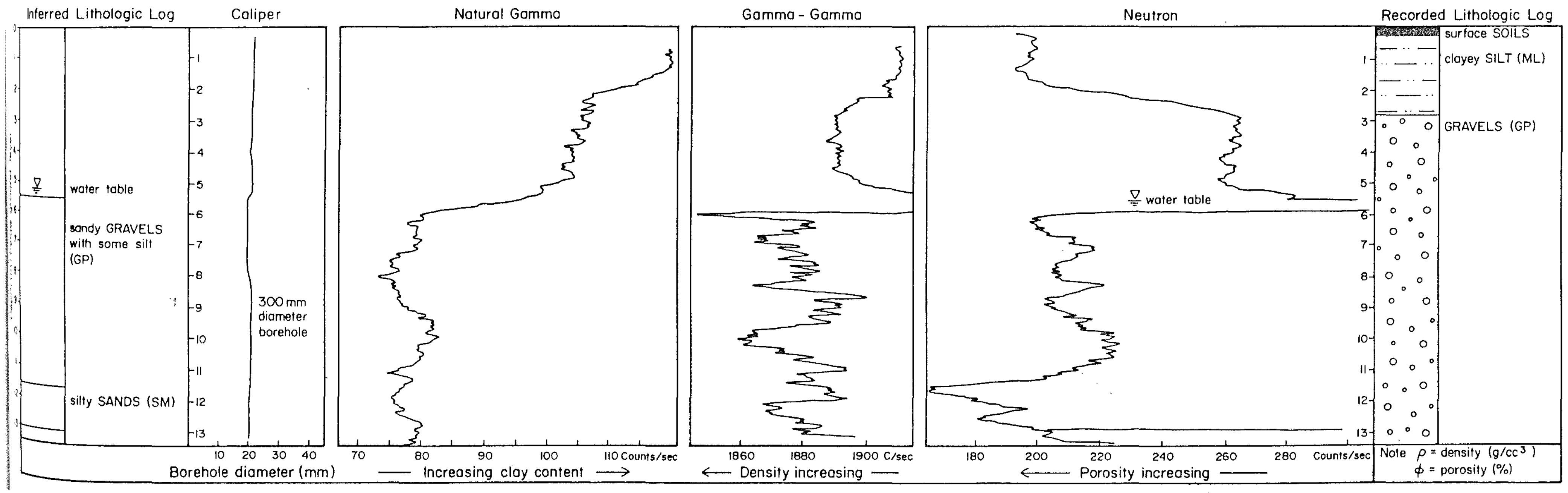



FIG B: LOGS OF BOREHOLE N32-101 (Spotswood)



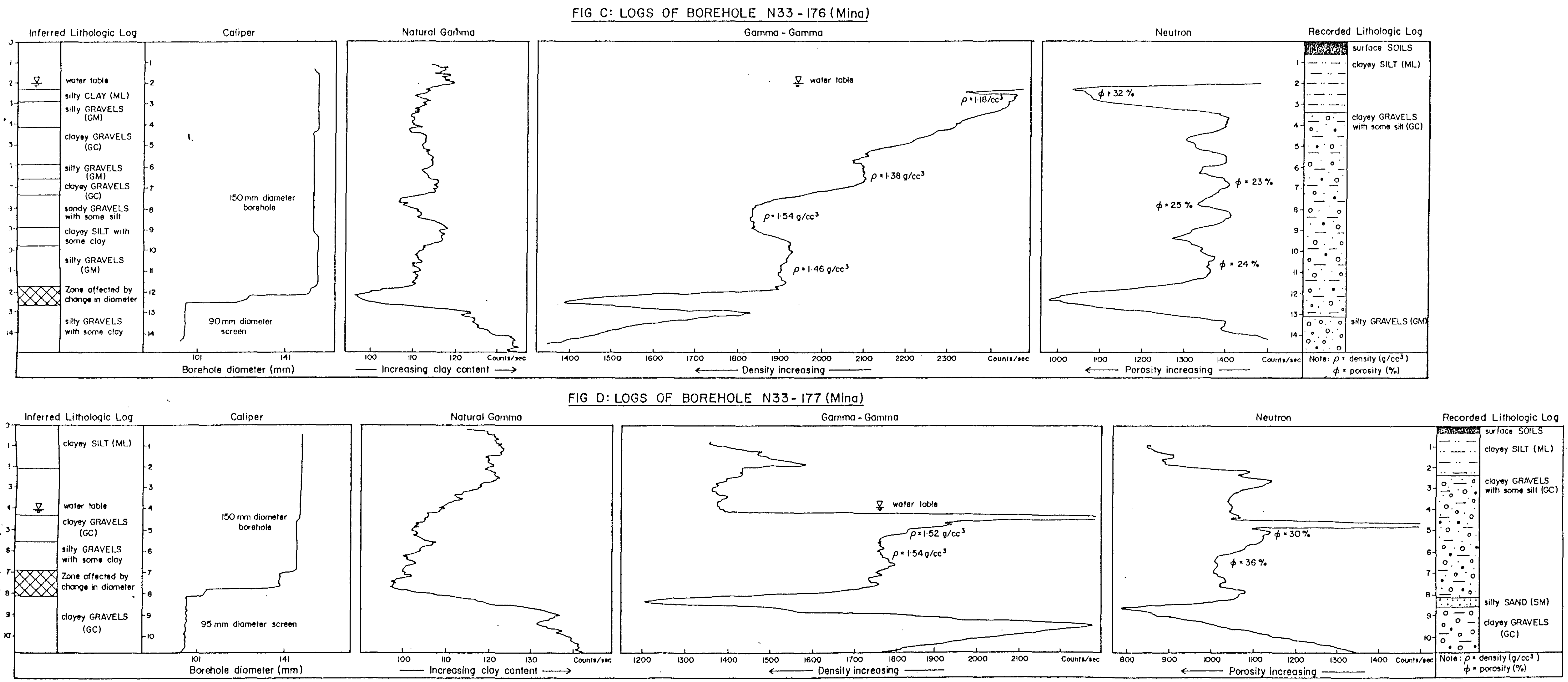



Fig 3.10. Nuclear log compilation for boreholes N33.176 and N33.177-Mina Plains

The interpreted lithologic log from bore 57 at Spotswood showed general agreement with the recorded material description, namely a surface silty clay layer 2.6 metres thick underlain by sandy gravels. The sandy gravel section is quite uniform upto 11.2 metres where a 2.8 metres thick layer of silts and sands is indicated by a significant increase in estimated porosity and smaller drops in clay content and density.

# CHAPTER 4 : HYDROGEOLOGICAL INVESTIGATIONS AND RESULTS

## 4.1 Background.

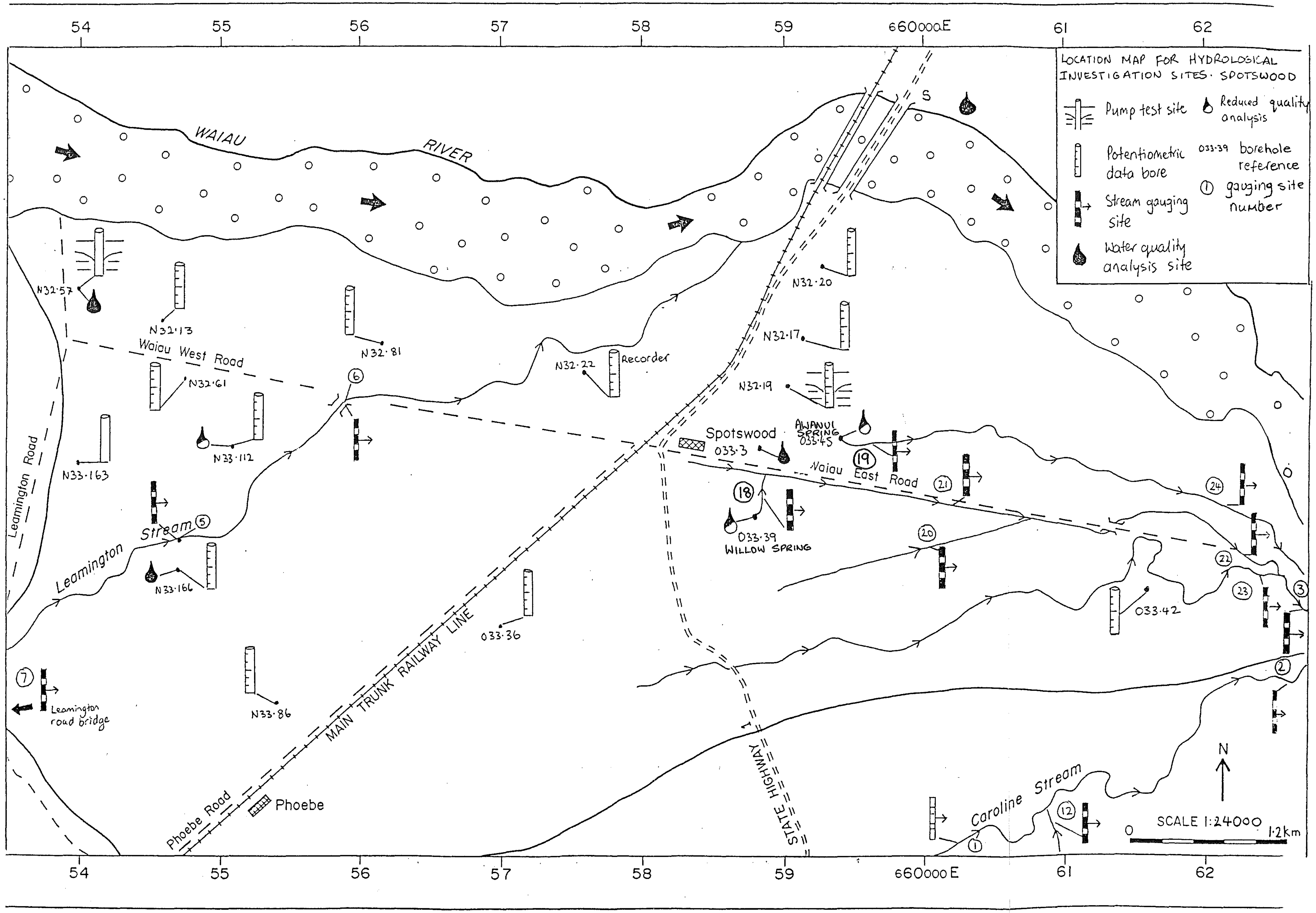
The aquifers within the Spotswood and Mina Plains are recharged from rainfall and the main tributaries of the region namely the Waiau River, Leamington, Crystal Brook and Mina Streams. The other tributaries of any consequence in the region, Swamp Stream and the Jed River have established courses which do not contribute to the aquifer system of the Mina Plains.

The period of record used in this analysis is from October 1986 to November 1987. During this period the average annual rainfall was 662 millimetres and the lowest period of rainfall occurred from November 1986 to January 1987. The total rainfall occurring in the region during the driest months of December 1986 and January 1987 exceeded 1 millimetre on only eight days (maximum recorded on 21$^{st}$ December 1986, 6 millimetres) resulting in the condition where evaporation was well in excess of any rainfall, evident in the extremely dry pasture land and the degree of irrigation undertaken by landowners (see Appendix 4.1 for data summary).

In September 1986 a monitoring programme was set up by staff of the North Canterbury Catchment Board and the writer to identify major trends and fluctuations within the groundwater system of the region. Of the thirty-five boreholes located and documented over the previous year, twenty-nine were selected to be monitored on a monthly basis. The monitoring programme was complemented by the installation of water level recorders at reference sites 033.8 (Mina) and 033.22 (Spotswood) in December 1986 (Fig 4.1).

In November 1986 the surface hydrology gauging programme was expanded to include seventeen stream sites in the Cheviot region. The seventeen sites were gauged by staff of North Canterbury Catchment Board on a monthly basis at times which coincided with the water level monitoring programme. A further seven sites were gauged by the writer in an attempt to obtain some correlation with the artesian system of the lower Spotswood plains and the flow of the Waiau River and Leamington Stream (Fig 4.1 & 4.2).

Fig 4.1. Location map for
hydrological investigation sites,
Spotswood Plains



54
55
56
57
58
59
660000E
61
62
LOCATION MAP FOR HYDROLOGICAL INVESTIGATION SITES. SPOTSWOOD
Pump test site
Reduced quality analysis
Potentiometric data bore
033·39 borehole reference
Stream gauging site
1 gauging site number
Water quality analysis site
WAIAU RIVER
S
N32·57
N32·13
N32·81
N32·20
N32·17
Waiau West Road
N32·61
N32·22
Recorder
N32·19
6
Spotswood
033·3
AWANUI SPRING 033·45
19
Waiau East Road
21
24
Leamington Road
N33·163
N33·112
18
033·39
WILLOW SPRING
20
22
23
3
Leamington Stream 5
N33·166
033·36
033·42
2
MAIN TRUNK RAILWAY LINE
7
Leamington road bridge
N33·86
STATE HIGHWAY 1
N
Caroline Stream
12
1
Phoebe Road
Phoebe
SCALE 1:24000
0
1·2km


FIG 4·1

In the dry period of November to January 1987 a large proportion of low flows are lost to recharge with all of the major streams namely Crystal Brook, Mina and Leamington Streams running dry, only the Waiau River maintains surface flow during this period. The quantities of groundwater withdrawn for irrigation on the Spotswood Plains are considerably less than the river recharge from the Waiau. Irrigation of the Mina Plains during the equivalent period is not sourced from local boreholes but from the County Council Supply borehole in Spotswood (reference Bore N32.57).

Potentiometric surveys of the aquifers were carried out during 1987 on a monthly basis at 29 borehole locations. The surveys were conducted to determine direction of groundwater flow and to locate recharge/discharge zones, obtain summer and winter hydraulic gradients and hence flow rates. The results of the surveys are presented as potentiometric contour maps for aquifer systems in each Plains area drawn from data presented in Appendix 4.2.

## 4.2 Aquifer Summary.

The geological evidence presented in Chapters 2 and 3 has identified has identified the principal aquiclude, aquifer and aquitard hydrogeologic units for the areas of Mina and Spotswood Plains, as follows;

(1) Aquiclude: The Mina and Spotswood Plains are underlain by the Greta Formation, a thick fine grained unit of predominantly silty clays with some sand (section 2.3.1). The most comprehensive account of this units water bearing qualities were recorded during the drilling of a borehole in Mina in 1899 (reference bore 033.10), which was sunk with the intention of supplying groundwater to a nearby freezing works factory. The material description log this bore records approximately 9 metres of sandy gravel underlain by a relatively impermeable silty clay material from 9 metres to the end of the bore at 232 metres, at which stage the drilling rods became stuck and the bore was abandoned (Appendix 2.1). No significant water-bearing strata were encountered which is in keeping with results from other bores drilled into this unit, for example reference bore N33.22 in Mina (Appendix 2.1).

(2) Aquifer: The Quaternary Units described in Chapter 2 consist of poorly to well sorted fluviatile derived gravels, sands and

Fig 4.2. Location map for hydrological investigation sites, Mina Plains

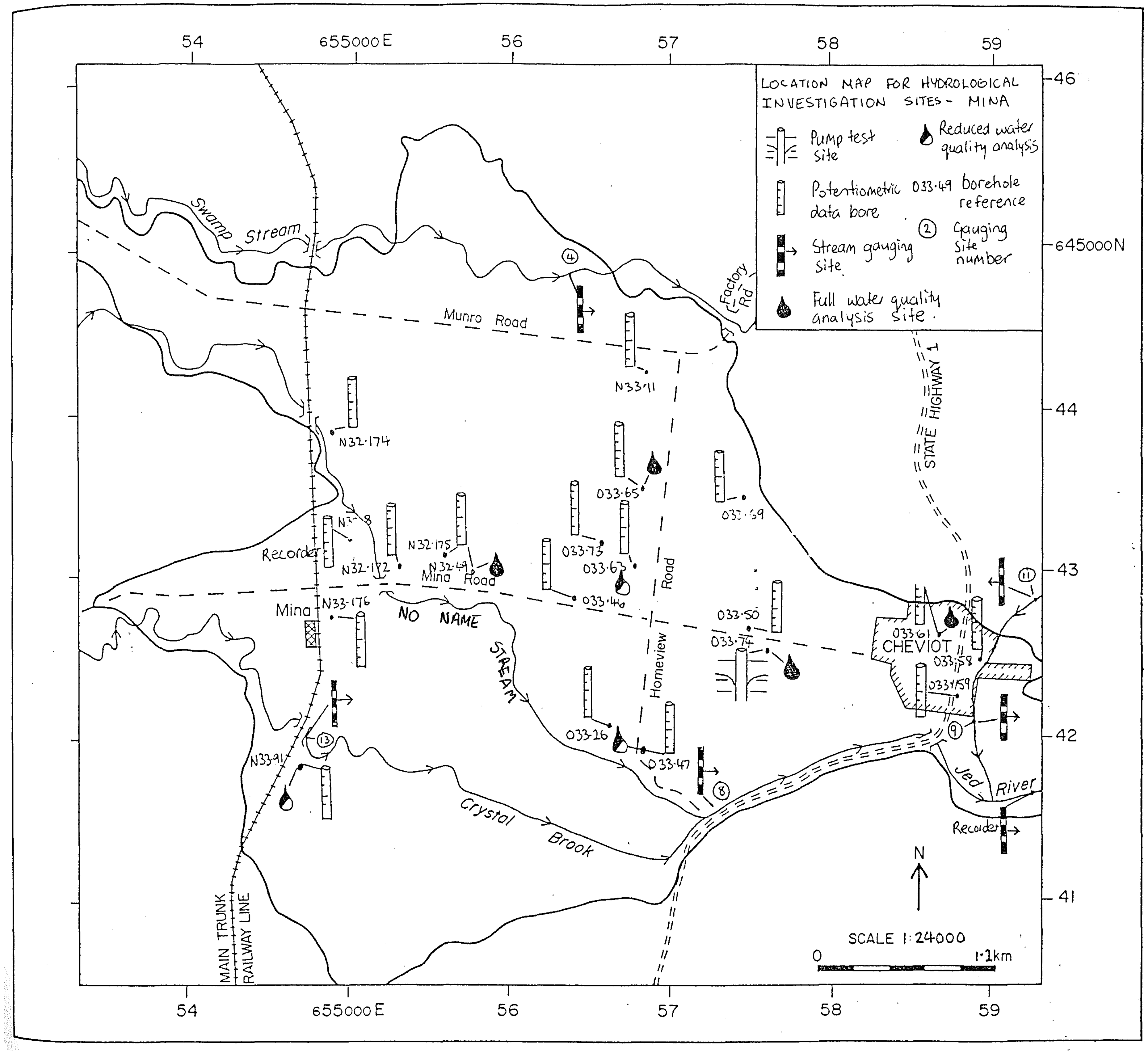

LOCATION MAP FOR HYDROLOGICAL INVESTIGATION SITES - MINA
Pump test site
Reduced water quality analysis
Potentiometric data bore
033·49 borehole reference
Stream gauging site
2 Gauging site number
Full water quality analysis site
54
655000E
56
57
58
59
46
645000N
44
43
42
41
Swamp Stream
Munro Road
Factory Rd
STATE HIGHWAY 1
N33·91
N32·174
033·65
033·69
033·73
033·63
033·46
N32·175
N32·49
N32·172
Recorder
Mina Road
Mina
N33·176
NO NAME STREAM
Homeview Road
033·50
033·74
033·61
CHEVIOT
033·58
033·59
033·26
033·47
Crystal Brook
Jed River
Recorder
MAIN TRUNK RAILWAY LINE
SCALE 1:24000
0
1·1km
N

FIG 4.2

silts which range from an average total thickness of 9 metres in Mina to greater than 35 metres in Spotswood (see section 3.3.8). Generally these units are better sorted, contain less fines and exhibit considerably higher permeabilities in Spotswood than in Mina, and this is reflected in the greater number of better yielding bores in the Spotswood area.

Unfortunately there are an insufficient number of material descriptions from bores in Spotswood and Mina to define separate aquifer units within the Quaternary Units, which leads to the general conclusion that based on geological evidence these formations are a collection of shallow discrete but interconnected thin minor aquifers.

(3) Aquitard: The aquifers of Spotswood and Mina Plains are overlain by an areally extensive layer of clayey silt (loess) which ranges in total thickness from 1 to 4 metres (section 2.3.1). Drilling has shown that the material is hard, consolidated and relatively impermeable. This material acts as an effective aquitard to direct recharge from rainfall except in areas where streams have incised channels into the underlying gravels (for example Crystal Brook, Mina, Swamp and Leamington Streams).

## 4.3 Surface Hydrology

### 4.3.1 Correlation Analysis

A North Canterbury Catchment Board Microtideda programme was used to correlate the data obtained from the surface gauging programme and the stage recorders installed on the Jed River and Leamington Stream (Table 4.1 a, b, c, based on Appendix 4.2). The results show that for the majority of gauging sites a correlation of greater than 0.85 exists with flows of the Jed and Leamington tributaries (gauging sites No's 1-5, 8, 11-17). Three gauging sites showed a poor correlation with the Jed but an acceptable correlation with the Leamington Stream (gauging sites No,s 6 and 7). Only two gauging sites (No,s 9 and 10) showed an acceptably high correlation with flow from either of the tributaries.

At gauging sites 9 and 10 a log-log correlation was run through the Microtideda programme. At site No 9 an improvement from 0.610 to 0.816 on the previous linear correlation was obtained. The log-log correlation at site 10 did not improve above 0.50, consequently data from this gauging site was not used in the determination of a regression equation (section 4.6.2).

Table 4.1a Linear and Log-Log Correlations of Stream Gauging Sites with Jed River, Leamington Stream and Waiau River (Mean Daily Flows)

| Stream River | Site Number 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Linear Correlation | | | | | | | | | | | | | | | | | |
| Jed | 0.996 | 0.973 | 0.981 | 0.743 | 0.948 | 0.510 | 0.549 | 0.991 | 0.305 | -0.028 | 0.939 | 0.863 | 0.975 | 0.841 | 0.912 | 0.887 | 0.840 |
| Leamington | 0.889 | 0.882 | 0.915 | 0.932 | 0.998 | 0.849 | 0.893 | 0.856 | 0.610 | 0.523 | 0.946 | 0.935 | 0.937 | 0.954 | 0.993 | 0.995 | 0.985 |

Table 4.1b Linear and log-log correlations of stream gauging sites from lower portion of Spotswood Plains with Leamington Stream and Waiau River (mean daily and weekly flows)

| | Site Number 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|
| Linear Correlation | | | | | | | |
| Leam/Daily | 0.246 | 0.041 | -0.063 | 0.691 | 0.738 | 0.821 | 0.686 |
| Leam/Weekly | 0.264 | -0.008 | 0.073 | 0.608 | 0.706 | 0.626 | 0.538 |
| Waiau/Daily | 0.279 | 0.349 | -0.232 | 0.667 | 0.427 | 0.766 | 0.445 |
| Waiau/Weekly | 0.321 | 0.742 | 0.283 | 0.448 | 0.274 | 0.395 | 0.404 |
| Lob-Log Correlation | | | | | | | |
| Leam/Daily | 0.226 | 0.097 | 0.178 | 0.743 | 0.671 | 0.582 | 0.630 |
| Leam/Weekly | 0.341 | 0.058 | 0.177 | 0.732 | 0.747 | 0.555 | 0.601 |
| Waiau/Daily | 0.365 | 0.532 | -0.146 | 0.695 | 0.454 | 0.698 | 0.572 |
| Waiau/Weekly | 0.428 | 0.756 | 0.286 | 0.544 | 0.366 | 0.665 | 0.568 |

Table 4.1c Linear correlation of stream gauging sites from lower portion of Spotswood Plains with respect to individual sites

| Site Number | Site Number 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|
| 18 | 0.093 | 0.350 | 0.213 | 0.611 | 0.217 | 0.161 |
| 19 | | 0.182 | 0.009 | -0.131 | 0.146 | 0.130 |
| 20 | | | -0.276 | -0.030 | -0.177 | -0.299 |
| 21 | | | | 0.790 | 0.832 | 0.842 |
| 22 | | | | | 0.674 | 0.751 |
| 23 | | | | | | 0.825 |

The Microtideda programme was also used to obtain linear correlation values for data gauged by the writer at seven sites in the lower portion of the Spotswood plains (Fig 4.1, Table 4.2). The area was of particular interest because of the number of permanent flowing springs located in the area.

Of the seven sites gauged by the writer, sites 22 and 23 showed reasonable linear correlations based on average daily flows of Leamington Stream and the Waiau River (Table 4.2). The poor correlations of gauging sites 18, 19, 20, 21, 24 to flows in either the Leamington or Waiau is due to their smaller cross-sectional area. Stream flow in these smaller gauging sites will be more greatly effected from hourly - daily fluctuations than will flow recorded in the main tributaries. Thus the average weekly flow rates from the Waiau and Leamington were used in the Microtideda programme and correlated to gauging site flow. The correlation value of site No 19 improved from 0.349 (Waiau daily flow) to 0.742 (Waiau weekly flow) which is an acceptable level for regression analysis. Applying a log-log correlation of the sites with stream/river flow an improvement from 0.608 to 0.732 was obtained at site 21.

Table 4.2 also lists correlation results of individual gauging sites. The correlation between the two spring sites, (No's 18 and 19) is noteworthy. Both spring sites show a poor correlation with daily flows of the Waiau and Leamington. However Site 19, the smaller of the springs shows a reasonable correlation with the Waiau weekly average flows. The poor correlation of both springs and the reasonable correlation of site No 19 with the Waiau indicate that the springs are sourced from different aquifers although investigative drilling would need to be carried out at site 18 to determine the nature of the aquifer.

4.3.2 Regression Analysis

The Microtideda programme was also used to obtain regression analysis equations at gauging sites which showed reasonable correlations (over 0.75) with daily/weekly average flows from either Leamington, Waiau or Jed Rivers and the equations are listed in Table 4.3. Having established regression equations mean daily flows from December 1986 to November 1987 were calculated based on the mean daily flow of the river or stream with which the gauging site showed the best correlation. The mean daily flows for gaugings carried out in Spotswood show that;

(1). The Leamington Stream loses 213 l/s into the groundwater system between gauging sites 5 and 6.

(2). Specific estimates of stream / spring gains and losses on the lower plains area are not possible due to the poor correlation obtained from a number of sites. However, Willow and Awanui springs discharge on average 30 and 5 l/s into channels which drain the lower Plains area. These channels gain approximately 170 and 50 l/s respectively to the point where they discharge into the Waiau River.

(3). Caroline Stream (Fig 4.1) gains approximately 50 l/s from gauging site No 2 to the point it discharges into the Waiau River.

The mean daily flows for gaugings carried out in Mina show that:

(4). Swamp Stream (Fig 4.2) gains 20 l/s between sites 14 and 4 along the length of the Northern limit of Mina plains. The Stream has incised a channel through the aquifer and presently flows on aquitard material. It does not contribute to the groundwater system of the Mina plains.

(5). The two main tributaries which transect the Mina plains (Crystal Brook and No - Name Stream ) collectively discharge 44 l/s upto gauging site No 8. From site No 8 to the recorder site along the Jed River there is a gain of 13 l/s.

(6). Woolshed Stream which flows through the Cheviot township gains 43.9 l/s from gauging site No 11 to site No 9.

## 4.4 Potentiometric Surveys

A potentiometric surface of an unconfined or confined aquifer is an imaginary surface coinciding with the hydrostatic pressure level of the water in the aquifer (Price 1985). Topography is the major control on whether an aquifer exists under unconfined or confined conditions, in aquifers systems where the hydraulic head exceeds the ground surface elevation flowing wells will develop.

### 4.4.1 The Spotswood Aquifer System

The potentiometric surveys of the aquifer system for the respective lowest (February 1987) and highest (August 1987) water levels based on data in Appendix 4.3 are presented as potentiometric contour maps with respect to mean sea level (figs 4.3 & 4.4). The contour patterns of both surveys do not cover the upper terrace surface aquifer because of insufficient observation boreholes. For the same reason it was necessary to

Table 4.2 Regression Analysis Equations

| Site | Equation | | Mean Daily Flow |
|---|---|---|---|
| 1 | -9.49 + 0.996 | Jed | 99.1 |
| 2 | 0.05 + 1.29 | Jed | 140.7 |
| 3 | 129 + 0.733 | Jed | 208.9 |
| 4 | -8.8 + 0.16 | Leamington | 64.2 |
| 5 | -13.0 + 1.16 | Leamington | 516.0 |
| 6 | -63.8 + 0.804 | Leamington | 302.8 |
| 7 | 30.8 + 0.639 | Leamington | 322.2 |
| 8 | -7.03 + 0.468 | Jed | 43.9 |
| 9 | 0.116 + 0.602 | Leamington (log) | 52.1 |
| 11 | 1.33 + 0.063 | Jed | 8.2 |
| 12 | 3.94 + 0.029 | Leamington | 17.2 |
| 13 | -1.71 + 0.168 | Jed | 16.6 |
| 14 | -5.16 + 0.109 | Leamington | 44.5 |
| 19 | -0.918 + 0.33 | Waiau (log) | 10.1 |
| 21 | 1.83 + 0.0956 | Leamington (log) | 121.0 |
| 22 | 2.03 + 0.061 | Leamington (log) | 175.0 |
| 23 | 3.65 + 0.032 | Leamington (log) | 18.7 |

| | Mean Daily Flows over year l/s | Mean Weekly flows l/s |
|---|---|---|
| Leamington | 456 | 3104.3 |
| Jed | 109 | |
| Waiau | 98676.3 | 671755 |

Fig 4.3 & 4.4. Potentiometric contour map of the Spotswood Plains for February (4.3) and August (4.4) 1987 in relation to metres above mean sea level

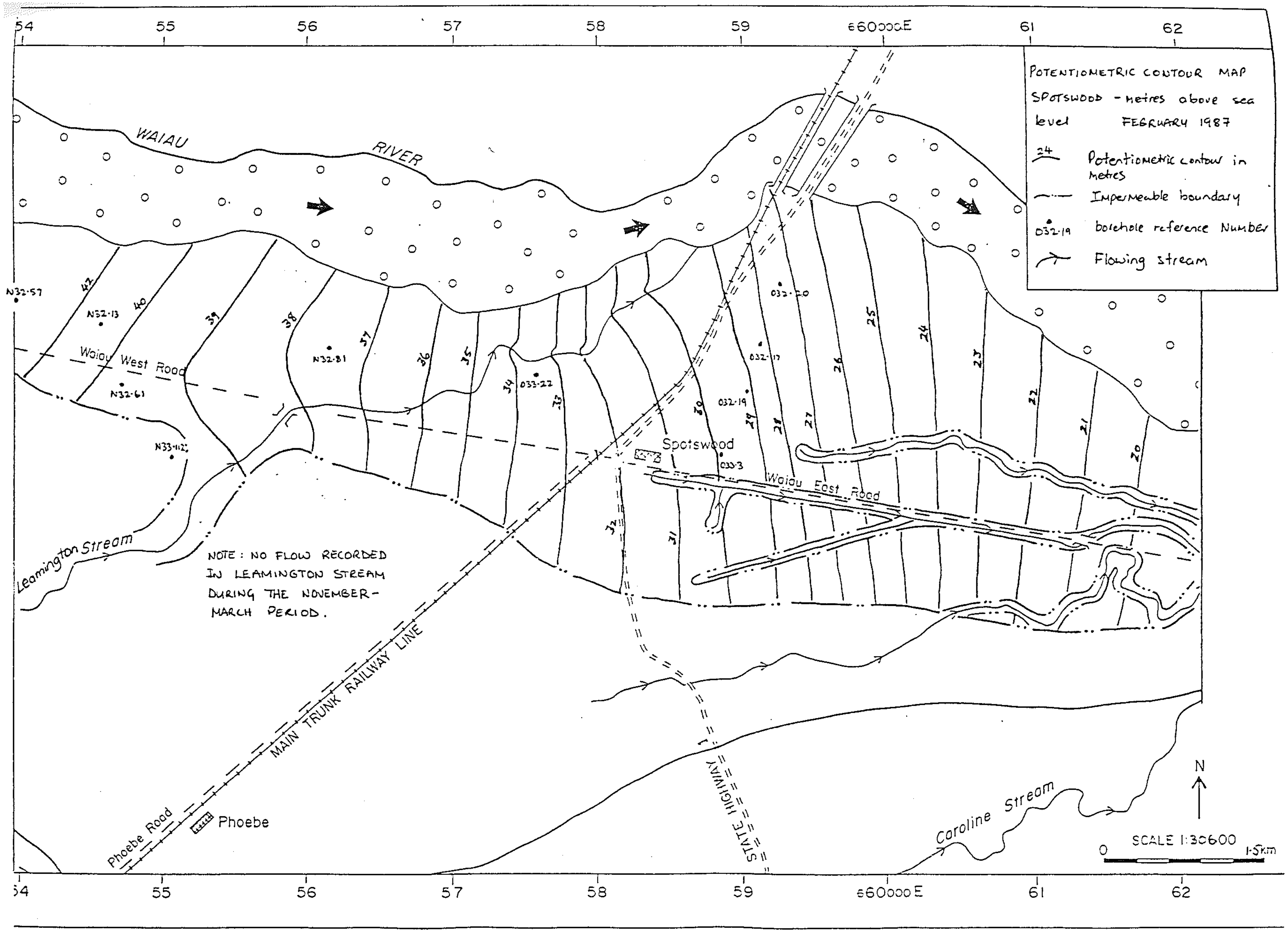

POTENTIOMETRIC CONTOUR MAP
SPOTSWOOD - metres above sea level FEBRUARY 1987
Potentiometric contour in metres
Impermeable boundary
borehole reference Number
Flowing stream
WAIAU RIVER
Waiau West Road
Waiau East Road
Spotswood
Leamington Stream
NOTE: NO FLOW RECORDED IN LEAMINGTON STREAM DURING THE NOVEMBER-MARCH PERIOD.
MAIN TRUNK RAILWAY LINE
STATE HIGHWAY 1
Phoebe Road
Phoebe
Caroline Stream
N
SCALE 1:30600
0
1.5km
660000E

FIG 4.3

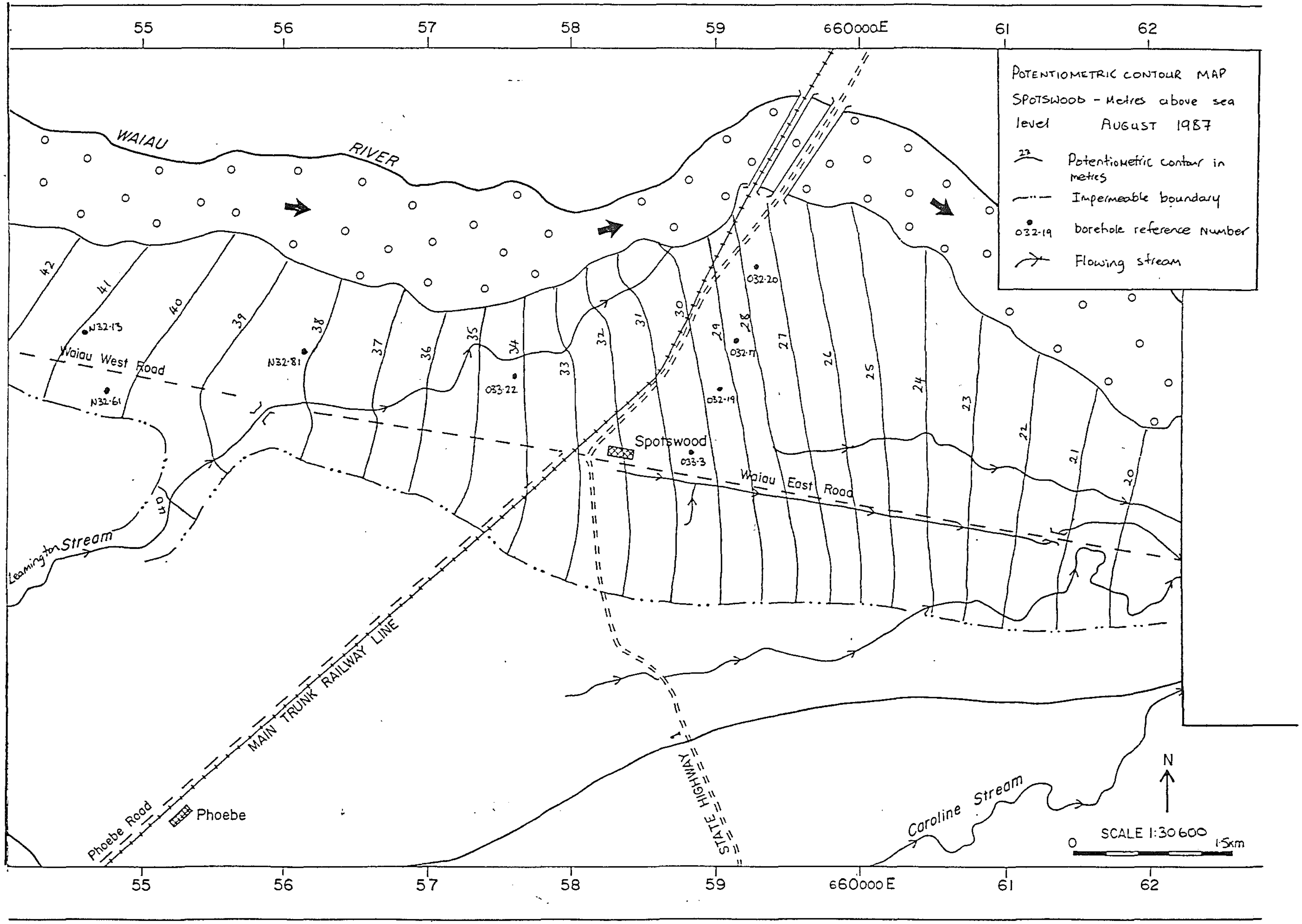

POTENTIOMETRIC CONTOUR MAP
SPOTSWOOD - Metres above sea level AUGUST 1987
Potentiometric contour in metres
Impermeable boundary
borehole reference number
Flowing stream
WAIAU RIVER
Waiau West Road
Waiau East Road
Spotswood
Leamington Stream
MAIN TRUNK RAILWAY LINE
STATE HIGHWAY 1
Phoebe Road
Phoebe
Caroline Stream
N32·13
N32·81
N32·61
033·22
032·20
032·17
032·19
033·3
SCALE 1:30600
0
1·5km
N
55
56
57
58
59
660000E
61
62

FIG 4.4

extrapolate the potentiometric contours on the lower portion of the Plains adjacent to the Waiau River.

The surveys indicate major recharge from the Waiau River infiltrating the aquifer system in the upper portion of the Plains along the southern boundary of the River. Recharge from the intermittent Leamington Stream to the aquifer system on the lower Spotswood Plains occurs in the August survey but not in the February survey as the stream has completely dried up along the length of its course in the region. In the lower portion of the Plains the contours indicate that the majority of the flow is back into the Waiau River, where a number of springs also confirm discharge from a confined aquifer.

The down valley piezometer curves from borehole reference N32.57 to the section where flow re-enters the Waiau River were used to measure the hydraulic gradient of the potentiometric surface. Fig 4.4 shows an increase in hydraulic gradient in the middle portion of the Plains which is due to recharge from Leamington Stream as it infiltrates the lower aquifer system.

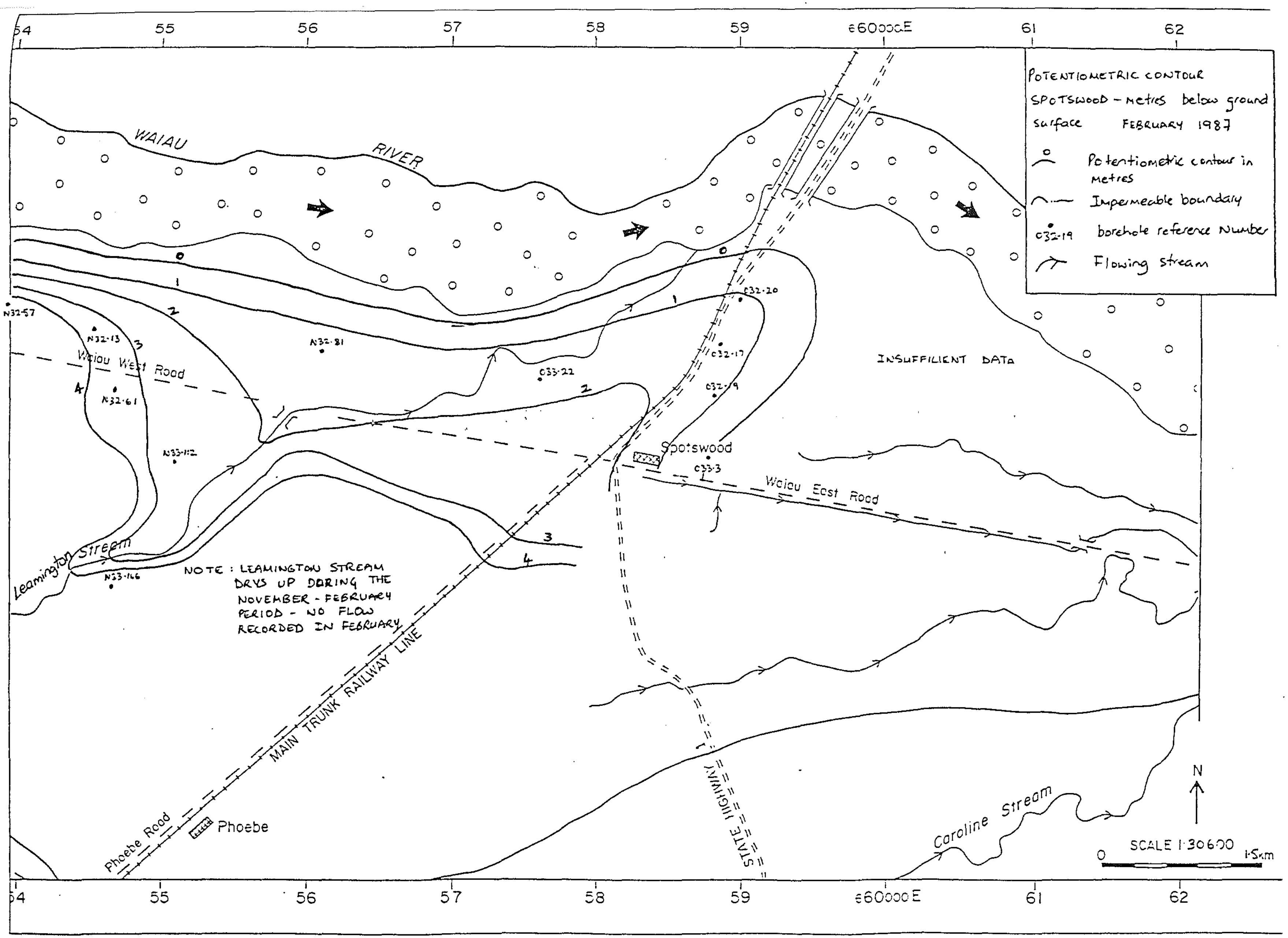
Straight line approximations give hydraulic gradients of 0.003 for February and 0.0045 for August 1987. The hydraulic gradient is steeper in the August survey giving a faster flow rate, meaning a greater discharge through the aquifer. The hydraulic gradients were used in conjunction with pumping tests to determine flow velocities (section 4.5.2 and Appendix 4.3 & 4.4).

Figs 4.5 & 4.6 illustrate the change in water levels between February and August 1987. The largest groundwater level changes occur in boreholes located some distance from the Waiau River outside the main zone of recharge. Water levels in bores on the higher older terraces adjacent to Leamington Stream show even greater changes due to the drying up of Leamington Stream in the dry period.

### 4.4.2 The Mina Aquifer System

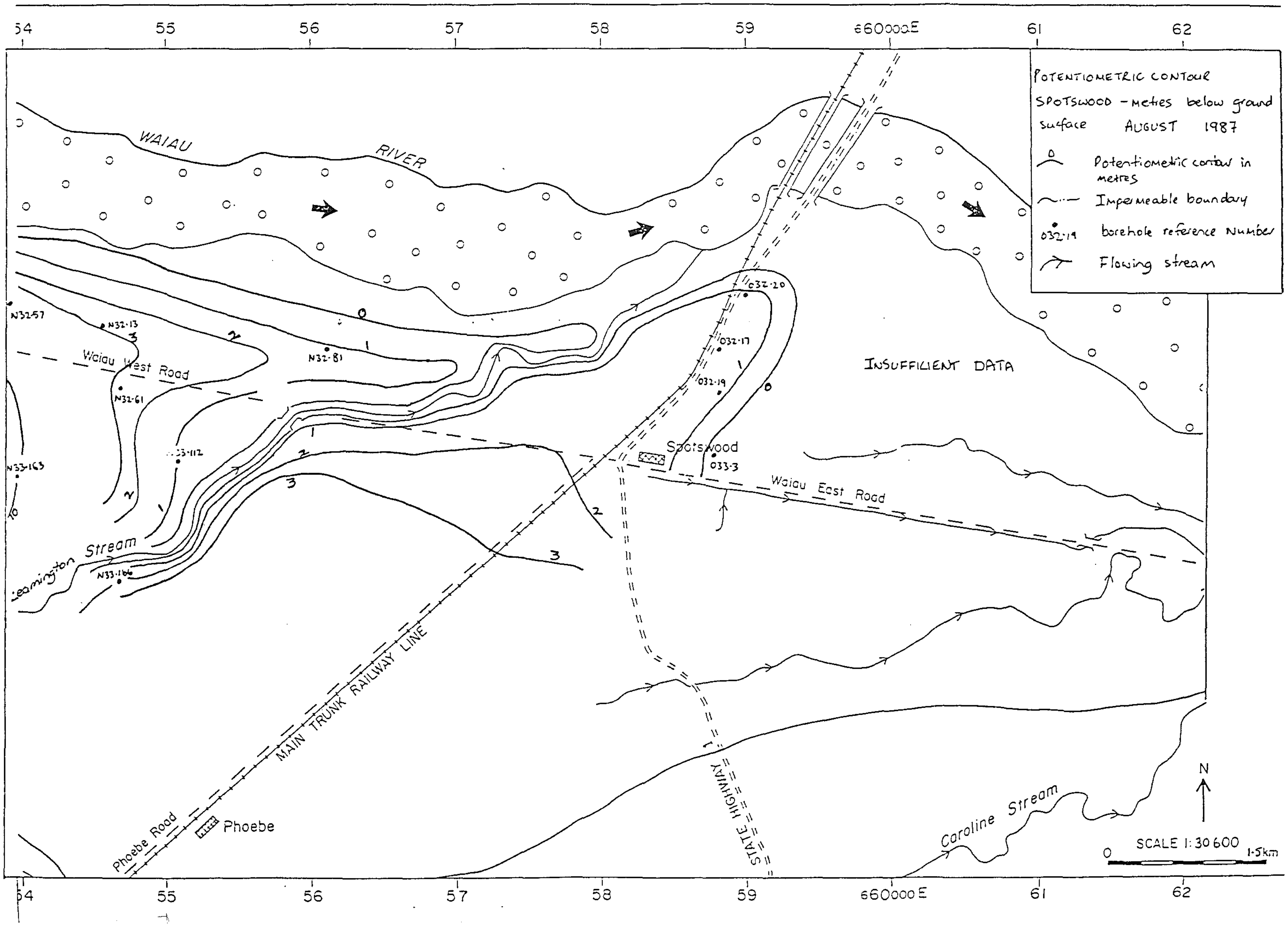
The February and August 1987 potentiometric surveys of the aquifer system within the Mina Plains are presented in Fig's 4.7 & 4.8. The contour patterns do not cover all the Plains surface because of an insuffi-

Fig 4.5 & 4.6. Potentiometric contour map of the Spotswood Plains for February (4.5) and August (4.6) 1987 in relation to metres below ground surface



POTENTIOMETRIC CONTOUR
SPOTSWOOD - metres below ground surface FEBRUARY 1987
Potentiometric contour in metres
Impermeable boundary
borehole reference Number
Flowing stream
WAIAU RIVER
INSUFFICIENT DATA
Waiau West Road
Waiau East Road
Spotswood
Phoebe
Phoebe Road
Leamington Stream
Caroline Stream
MAIN TRUNK RAILWAY LINE
STATE HIGHWAY
NOTE: LEAMINGTON STREAM DRYS UP DURING THE NOVEMBER - FEBRUARY PERIOD - NO FLOW RECORDED IN FEBRUARY
N32·57
N32·13
N32·61
N32·81
N33·112
N33·146
O33·22
O32·20
O32·17
O32·19
O33·3
O32·19
SCALE 1:30600
0
1·5km
N
54
55
56
57
58
59
60000E
61
62


FIG 4.5



POTENTIOMETRIC CONTOUR
SPOTSWOOD - metres below ground surface AUGUST 1987
Potentiometric contour in metres
Impermeable boundary
032·19 borehole reference Number
Flowing stream
WAIAU RIVER
INSUFFICIENT DATA
Waiau West Road
Waiau East Road
Leamington Stream
Caroline Stream
Spotswood
Phoebe
Phoebe Road
MAIN TRUNK RAILWAY LINE
STATE HIGHWAY 1
N32·57
N32·13
N32·81
N32·61
N33·163
N33·166
032·20
032·17
032·19
033·3
660000E
SCALE 1:30 600
0
1·5km
N


FIG 4.6

cient number of boreholes south-west of Crystal Brook Stream and north-west of the intersection of the Main Trunk Railway line and Munro Road.

The contours of February and August 1987 reflect a similar regional pattern but differ in that the saturated thickness of the aquifer in the upper portions of the area where the aquifer exists under unconfined conditions (reference bore N33.177, Appendix 2.1) decreases in February, resulting in a sympathetic shift of the contour pattern down slope. Figs 4.7 & 4.8 also show that the fluctuations in the lower portions of the Plains where the aquifer exists under confined conditions (section 4.7.4) are smaller than the fluctuations recorded in the upper portion of the Plains.

The contours in Fig 4.8 indicate flow and therefore recharge from Crystal Brook and Mina Streams to the aquifer enabling recovery of water levels which drop markedly in the February survey. In the lower portion of the Plains from the Homeview Road area to approximately 400 metres West of reference borehole 033.74 the contours close to form a 'sink' or discharge area within the Quaternary gravels. Discharge outlets include several ephemeral springs, one household supply bore and drainage courses along Mina Road. During periods of rainfall over several days especially in the winter months when groundwater levels are at their highest, recharge exceeds discharge and the area floods.

Based on the down valley piezometric curves of the potentiometric surface in the Mina aquifer from the Munro Road/Main Trunk Railway line intersection to Homeview Road and Homeview Road to just west of the Cheviot township for February and August the average hydraulic gradient for February is 0.003 and for August 0.005 (Appendix 4.4).

Fig 4.9 & 4.10 illustrate the change in water levels between February and August 1987, and show that the largest groundwater level changes occur towards the aquifers north-western margin which reflect the drop in recharge rate from the local streams during the summer.

## 4.5 Groundwater Fluctuations

### 4.5.1 Methodology

Water level records in 28 observation bores were collected on a monthly basis at locations in Mina and Spotswood over the period December

Fig 4.7 & 4.8. Potentiometric contour map of the Mina Plains for February (4.7) and August (4.8) 1987 in relation to metres above mean sea level

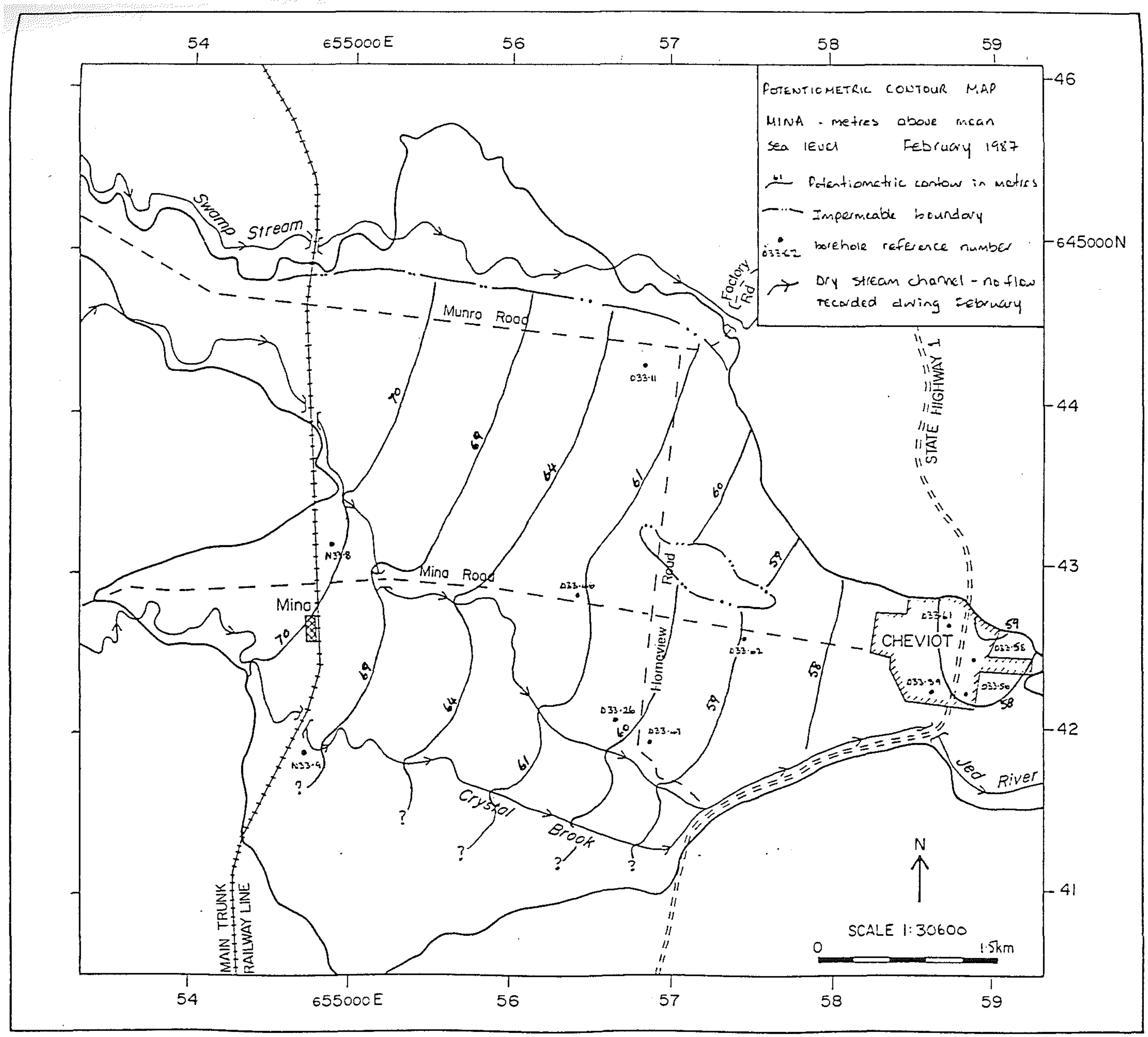
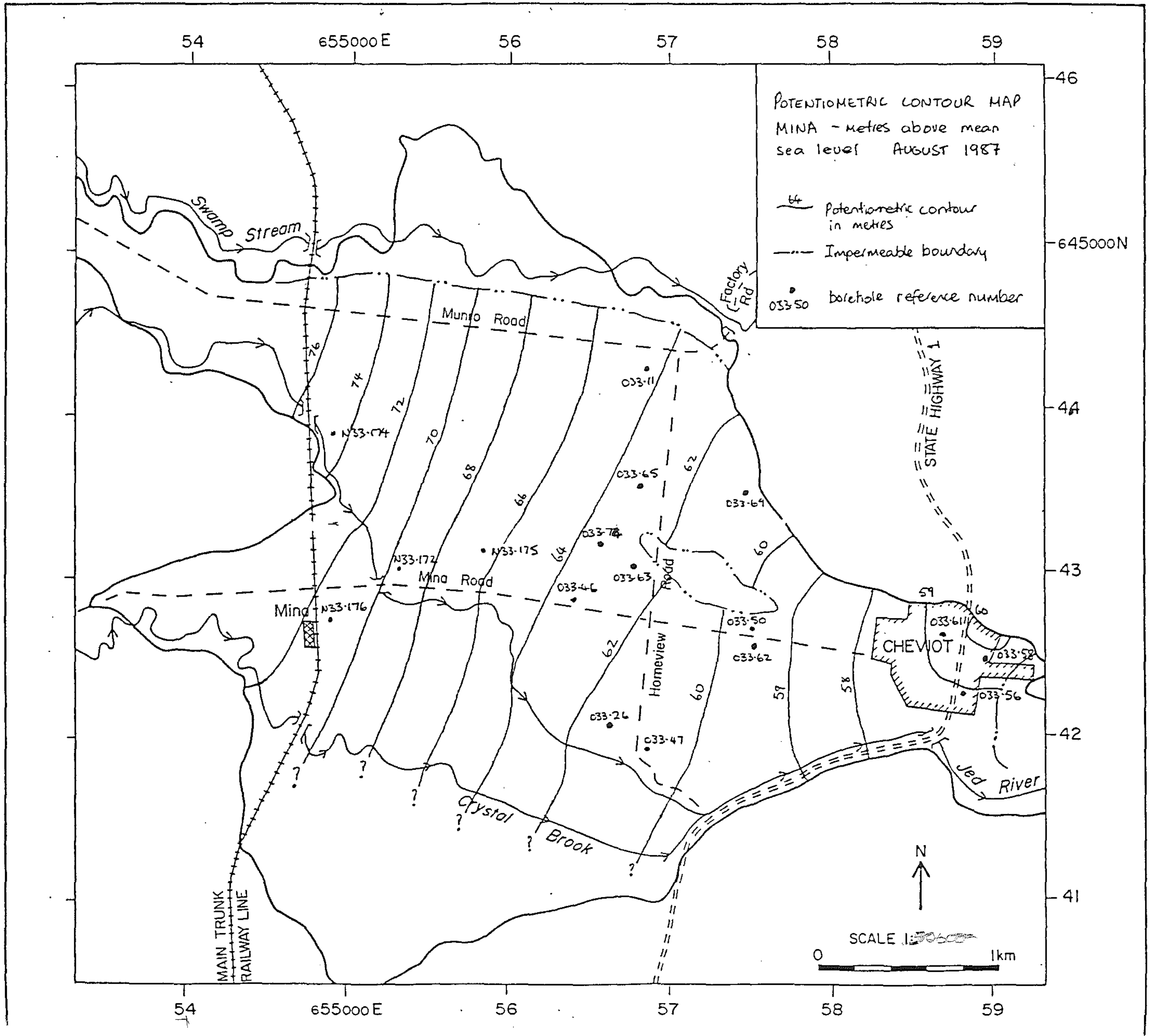

POTENTIOMETRIC CONTOUR MAP
MINA - metres above mean sea level February 1987
Potentiometric contour in metres
Impermeable boundary
borehole reference number
Dry stream channel - no flow recorded during February
655000E
645000N
Swamp Stream
Munro Road
Factory Rd
Mina Road
Mina
Homeview Road
STATE HIGHWAY 1
CHEVIOT
Crystal Brook
Jed River
MAIN TRUNK RAILWAY LINE
SCALE 1:30600
1·5km
N

FIG 4.7



POTENTIOMETRIC CONTOUR MAP
MINA - metres above mean sea level AUGUST 1987
64 Potentiometric contour in metres
Impermeable boundary
033·50 borehole reference number
54
655000 E
56
57
58
59
46
645000N
44
43
42
41
Swamp Stream
Munro Road
Factory Rd
STATE HIGHWAY 1
Mina Road
Mina
Homeview Road
CHEVIOT
Jed River
Crystal Brook
MAIN TRUNK RAILWAY LINE
N33·174
N33·172
N33·175
N33·176
033·11
033·65
033·69
033·63
033·46
033·50
033·62
033·611
033·58
033·56
033·26
033·47
76
74
72
70
68
66
64
62
60
59
58
N
SCALE
0
1km


FIG 4.8

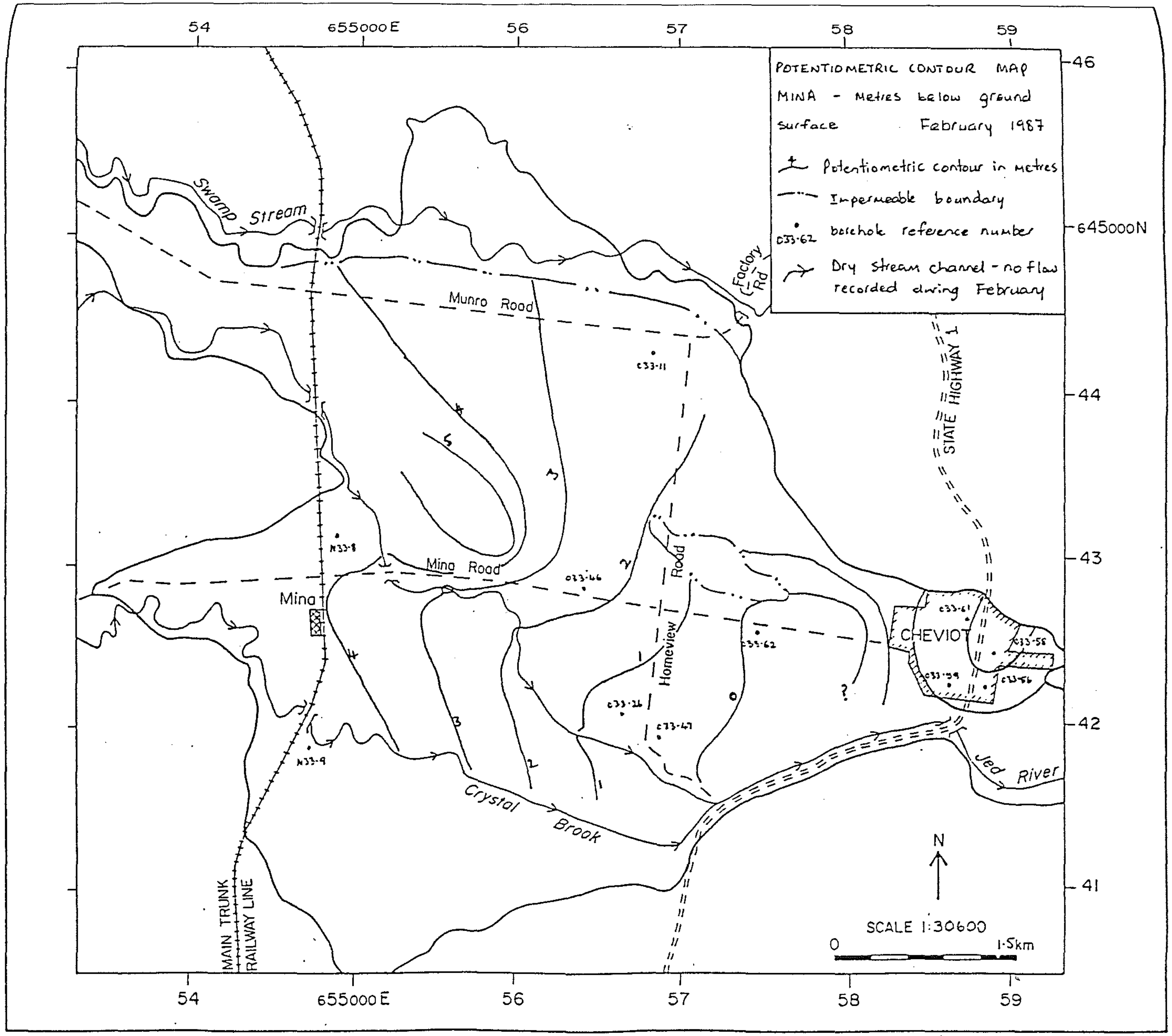



Fig 4.9 & 4.10. Potentiometric contour map of the Mina Plains for February (4.9) and August (4.10) 1987 in relation to metres below ground surface

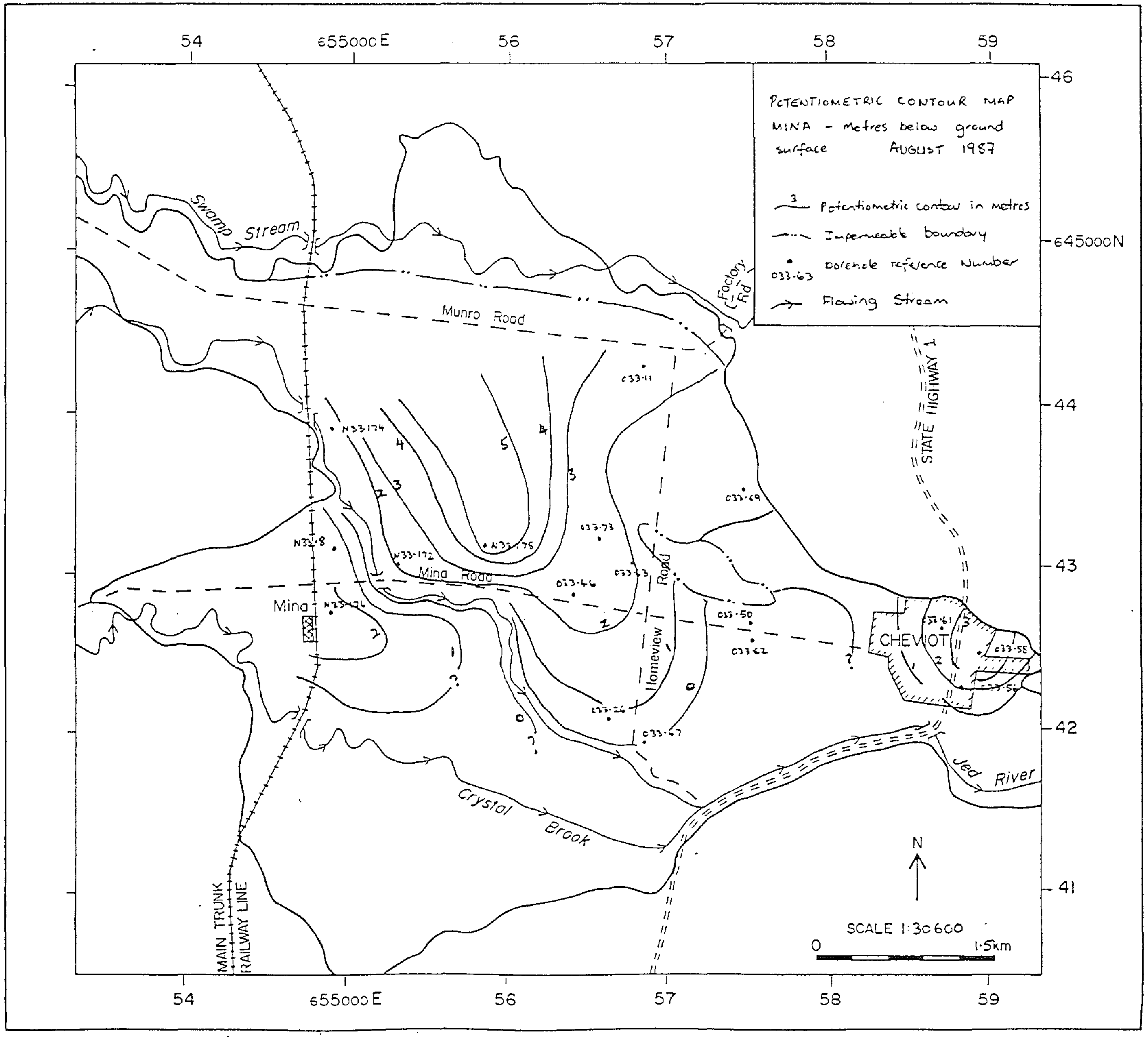

POTENTIOMETRIC CONTOUR MAP
MINA - Metres below ground surface AUGUST 1987
Potentiometric contour in metres
Impermeable boundary
Borehole reference Number
O33·63
Flowing Stream
Swamp Stream
Munro Road
Factory Rd
STATE HIGHWAY 1
Mina Road
Mina
Homeview Road
CHEVIOT
Crystal Brook
Jed River
MAIN TRUNK RAILWAY LINE
N
SCALE 1:30600
0
1·5km
54
655000E
56
57
58
59
46
645000N
44
43
42
41

FIG 4.10

1986 to November 1987. The data have been used to construct potentiometric contour maps (section 4.4) and stage height hydrographs which assist in determining how different areas of aquifer are affected by external influences such as rainfall and river levels (Appendix 4.5).

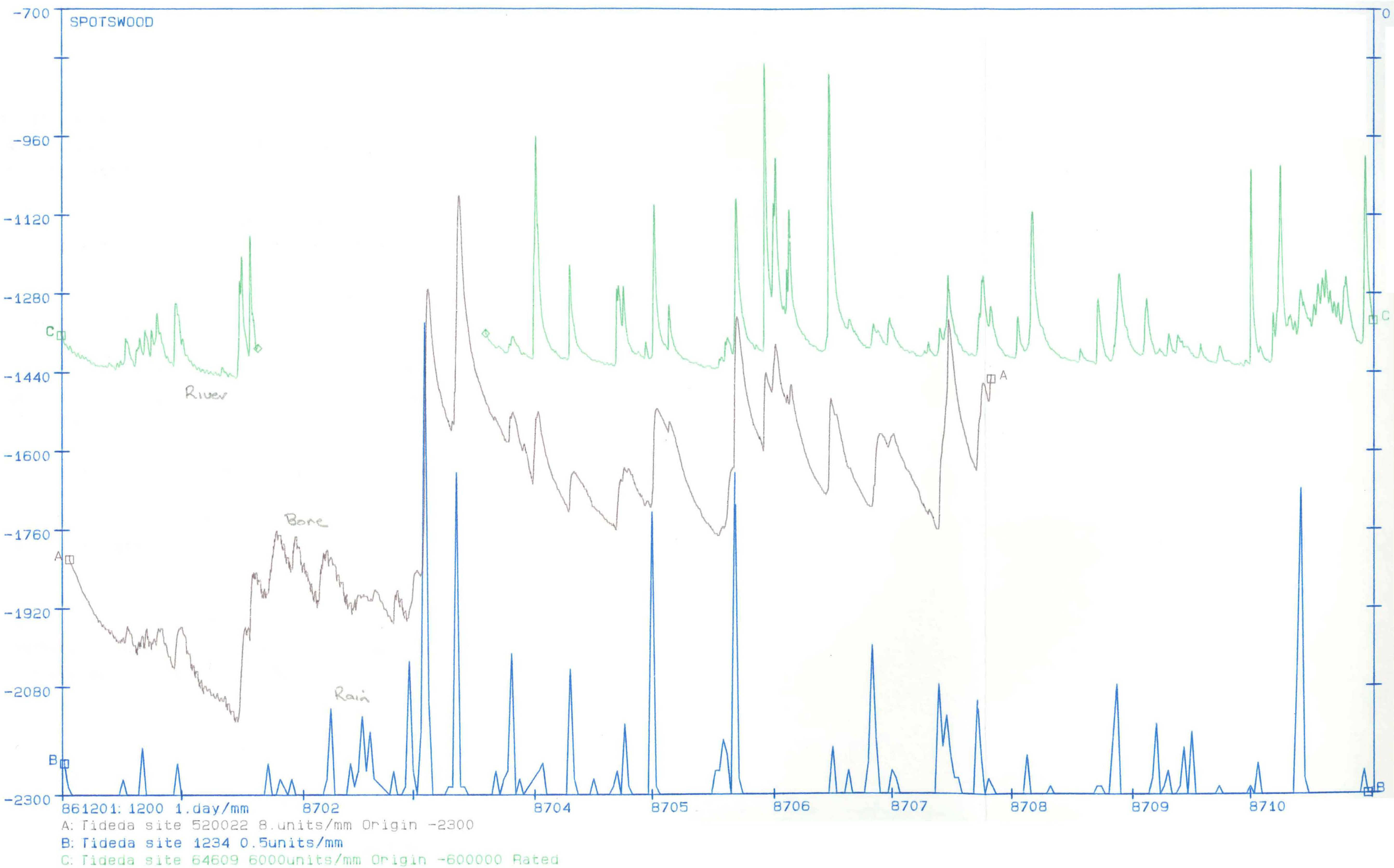
A saturated aquifer will respond to external influences such as rainfall by a rise in hydraulic head (h), which implies an increase in fluid pressure and an decrease in effective stress. Within an unconfined aquifer releases from storage represent an actual dewatering of the soil pores, whereas releases from storage in confined aquifers represent only the secondary effects of water expansion and aquifer extraction caused by changes in the fluid pressure. This has important implications in the drilling of boreholes for groundwater supply as a greater yield can be obtained in an unconfined aquifer than in a confined aquifer, with smaller changes in hydrostatic head over less extensive areas.

Of the 19 groundwater hydrographs constructed with the North Canterbury Catchment Board's Microtideda programme borehole reference N33.8 (Mina) and 033.22 (Spotswood) were chosen as typical annual hydrographs of groundwater fluctuations because water level recorders had been installed on these bores thus providing the most complete record of groundwater levels in the area.

4.5.2 The Spotswood Aquifer

A water level recorder was established 300 m from the East bank of the Waiau River which together with the recorder on the Waiau River at the lower gorge enabled the independent effects of the river on the aquifer to be assessed. A rainfall recorder was also installed at Cheviot School to assess the effect of rainfall percolating into the aquifer (Fig 4.11). The general pattern is one of steadily declining water levels from December to February reflecting the summer recession of the Waiau River and Leamington Stream and recovery from March due to recharge from the higher winter flows of the Waiau and Leamington. The Waiau River is the effective source of recharge during the summer months. This is evidenced by the near instantaneous rise in water levels in mid January 1987 in response to peak flows in the Waiau during a period of no rainfall. The anomaly is explained by periodic flood events associated with the snowmelt of water from the of the Southern Alps.

Fig 4.11. Plot of waterlevel
recorded at bore N33.22-flow of
Waiau River (site 64609) and rain-
fall (site 1234), Spotswood Plains


SPOTSWOOD
-700
-960
-1120
-1280
-1440
-1600
-1760
-1920
-2080
-2300
0
River
Bore
Rain
861201: 1200 1.day/mm
8702
8704
8705
8706
8707
8708
8709
8710
A: Tideda site 520022 8.units/mm Origin -2300
B: Tideda site 1234 0.5units/mm
C: Tideda site 64609 6000units/mm Origin -600000 Rated

The close correspondence of water levels in borehole 033.22 and stage height in the Waiau River indicates that the aquifer of the lower Spotswood Plains immediately adjacent to the Waiau River are effectively a subsurface flow extension of the waters of the Waiau River and Leamington Stream. A rainfall source of recharge is also shown by the good correlation between rainfall and the fluctuates superimposed on the aquifer hydrograph. The rapid rise with rainfall confirms the aquifer is affected by atmospheric pressure (see section 4.5.4).

### 4.5.3 Flow Nets

Flow nets are comprised of flow lines (path taken by individual particles of water) and equipotentials (lines of constant hydraulic head). For isotropic materials the flow net has two properties;

(1) flow lines are drawn orthogonal to equipotentials, and

(2) if any zone is drawn in a rectalinear square then all other zones should also be rectalinear squares.

Based on these conditions flow lines were drawn by trial and error approximations for the Plains area of Spotswood and Mina (Figs 4.12 & 4.13).

The August 1987 potentiometric contour map was chosen as pumping tests had been carried out in that month, and the values of transmissivity used in the following equations is based on the saturated thickness of that period.

Given the hydraulic gradient'i' the constant flow'Q'between flow lines is determined by;

$$Q = T\ i\ W \qquad \text{Equation 4.1}$$

where Q = total flow, $m^3$ /min

T = transmissivity

i = hydraulic gradient

W = width of flow tube, metres.

The recharge through the river bank in the upper portion of the Spotswood Plains was calculated, thus (Appendix 4.3),;

$$Q = T\ i\ l\ \sin\theta \qquad \text{Equation 4.2}$$

where l = length of river recharge reach

sin θ = angle groundwater flow lines make with the river bank.

The geometry of the flow net in Spotswood, together with the transmissivity (calculated in section 4.6) and head loss, enables the total flow in the aquifer section to be calculated (Appendix 4. ).

The flow net in Fig 4.12 is based on potentiometric data from a

Fig 4.12 & 4.13. Flow net for Spotswood (4.12) and Mina (4.13) Plains based on potentiometric data surveyed on 14th August 1987

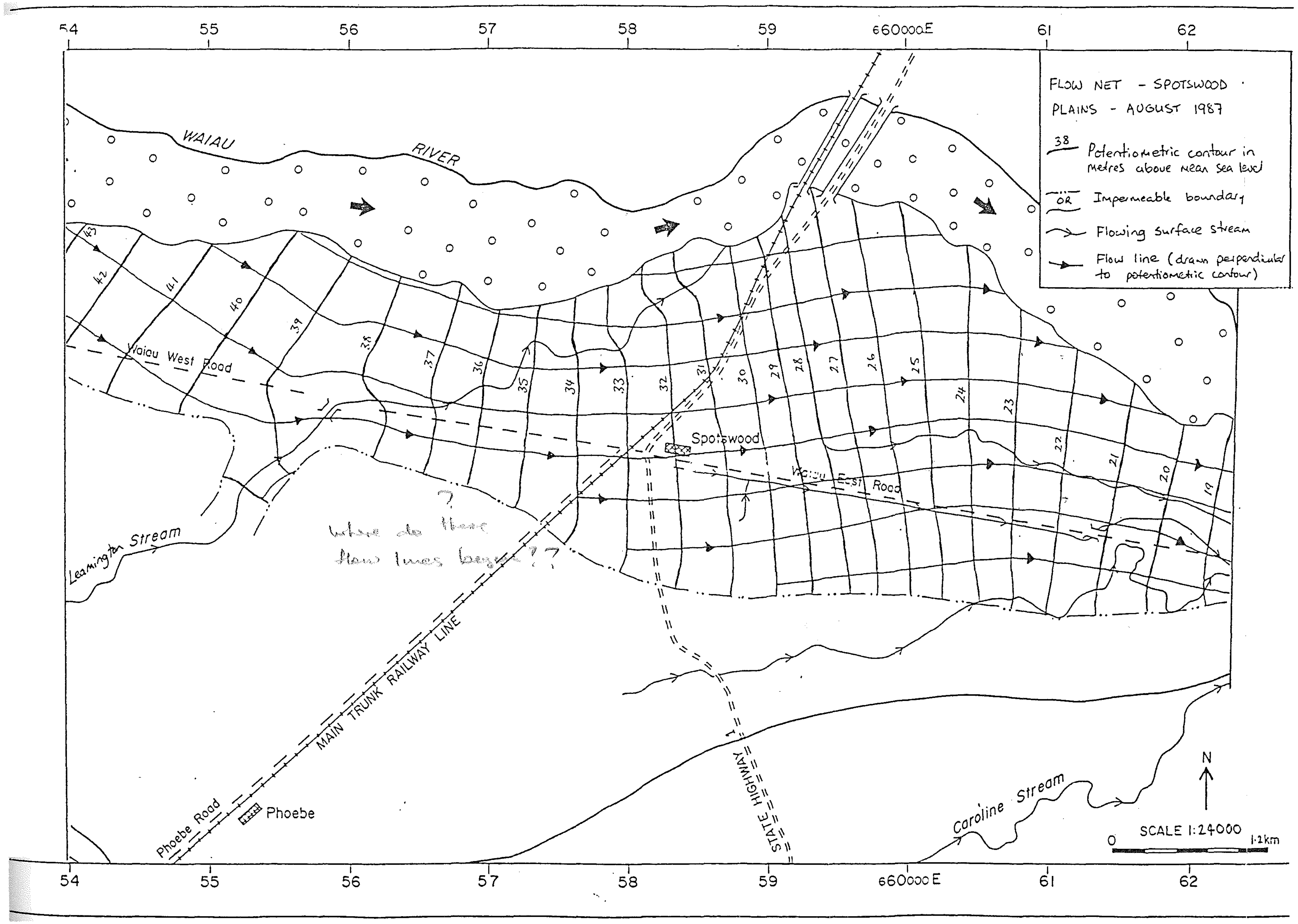
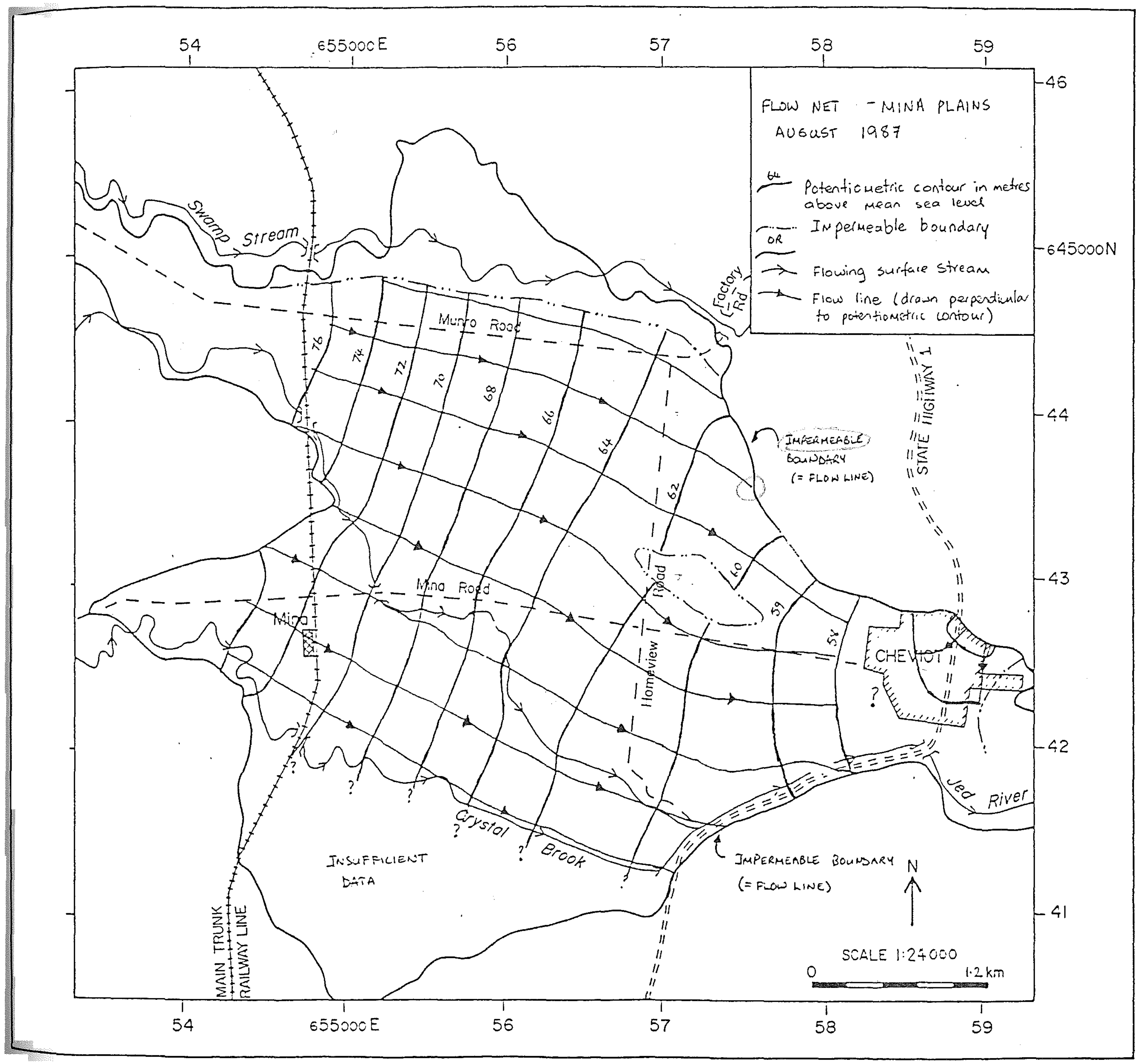

FLOW NET - SPOTSWOOD PLAINS - AUGUST 1987
38 Potentiometric contour in metres above mean sea level
OR Impermeable boundary
Flowing surface stream
Flow line (drawn perpendicular to potentiometric contour)
WAIAU RIVER
Waiau West Road
Waiau East Road
Spotswood
Leamington Stream
MAIN TRUNK RAILWAY LINE
STATE HIGHWAY 1
Phoebe Road
Phoebe
Caroline Stream
? where do these flow lines begin??
SCALE 1:24000
0
1.2km
N
54
55
56
57
58
59
660000E
61
62

FIG 4.12



FLOW NET - MINA PLAINS
AUGUST 1987
Potentiometric contour in metres above mean sea level
Impermeable boundary
OR
Flowing surface stream
Flow line (drawn perpendicular to potentiometric contour)
Swamp Stream
Munro Road
Mina Road
Mina
Factory Rd
Homeview Road
STATE HIGHWAY 1
IMPERMEABLE BOUNDARY (= FLOW LINE)
CHEVIOT
Jed River
Crystal Brook
INSUFFICIENT DATA
MAIN TRUNK RAILWAY LINE
IMPERMEABLE BOUNDARY (= FLOW LINE)
N
SCALE 1:24000
0
1·2 km
655000E
645000N


FIG 4·13

groundwater survey carried out in August 1987, and shows that at the time of survey the Waiau River and Leamington Stream discharged a total 'Q' of 38.34 $m^3$/min and 8.89 $m^3$/min respectively to the aquifer system, thus a total recharge to the aquifer system of 47.33 $m^3$/min. The total flow 'Q' discharging from the aquifer system is comprised of subsurface flow which re-enters the Waiau River and discharge from bores, springs and streams. As the survey was carried out in August it is assumed that there would be no extraction from local bores for irrigation purposes. The subsurface flow was calculated at 28.81 $m^3$/min and the surface flow obtained from gaugings carried out on that day namely 10.04 (site 22), 1.08 (site23) and 7.28 (site 24, see Appendix 4.3), which totals 46.51 $m^3$/min as total Q discharging the Plains. The net value of recharge (47.33 $m^3$/min) and discharge (46.51 $m^3$/min) is 0.82 $m^3$/min (or 13.6 $ls^{-1}$). This value of net recharge and discharge represents a crude but useful approximation of the hydrological equilibrium of the aquifer system in Spotswood.

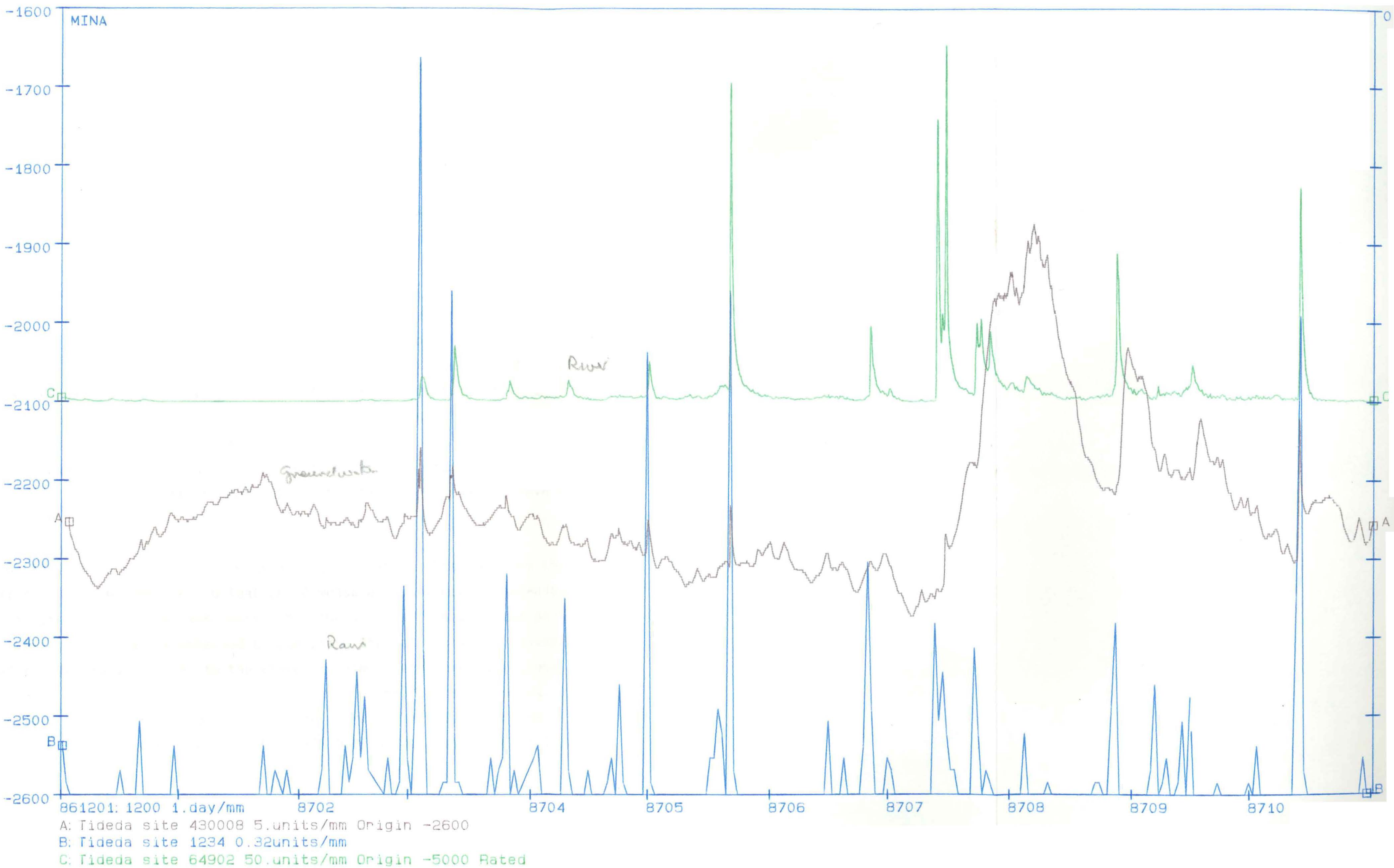
### 4.5.4 The Mina Aquifer

A water level recorder was established on borehole reference N33.8, 70 m from Mina Stream which is one of two intermittent streams that flow across the upper portion of the Mina Plains (Fig 4.2). The water level results, together with the rainfall recorder and the stage height recorder installed on the Jed River approximately 7 km down gradient enabled the independent effects of rainfall to be accessed (Fig 4.14).

The excellent response of river flow to rainfall was expected, the trend of water levels especially in the December 1986 to February 1987 period were not expected (Fig 4.14). For instance, a rise in groundwater level was recorded at site N33.8 during January 1987 yet in this month rainfall had not been recorded for 22 days and all streams in the area had dried up. Groundwater levels in bores within 200 metres of bore 8 (46 and 91) all show a reduction in waterlevels as waterlevels in bore 8 were rising and the preferred explanation is that the records are in error.

The water level in bore 8 steadied during February, and then slowly declined during the following 7 months. Mid way through July groundwater levels rose significantly in response to recharge from rainfall.

Fig 4.14. Comparative plot of water level recorded at bore N32.8 and flow of Jed River (site 64902) and rainfall (site 1234), Mina Plains


MINA
-1600
-1700
-1800
-1900
-2000
-2100
-2200
-2300
-2400
-2500
-2600
River
Groundwater
Rain
A
B
C
0
8702
8704
8705
8706
8707
8708
8709
8710
861201: 1200 1.day/mm
A: Tideda site 430008 5.units/mm Origin -2600
B: Tideda site 1234 0.32units/mm
C: Tideda site 64902 50.units/mm Origin -5000 Rated

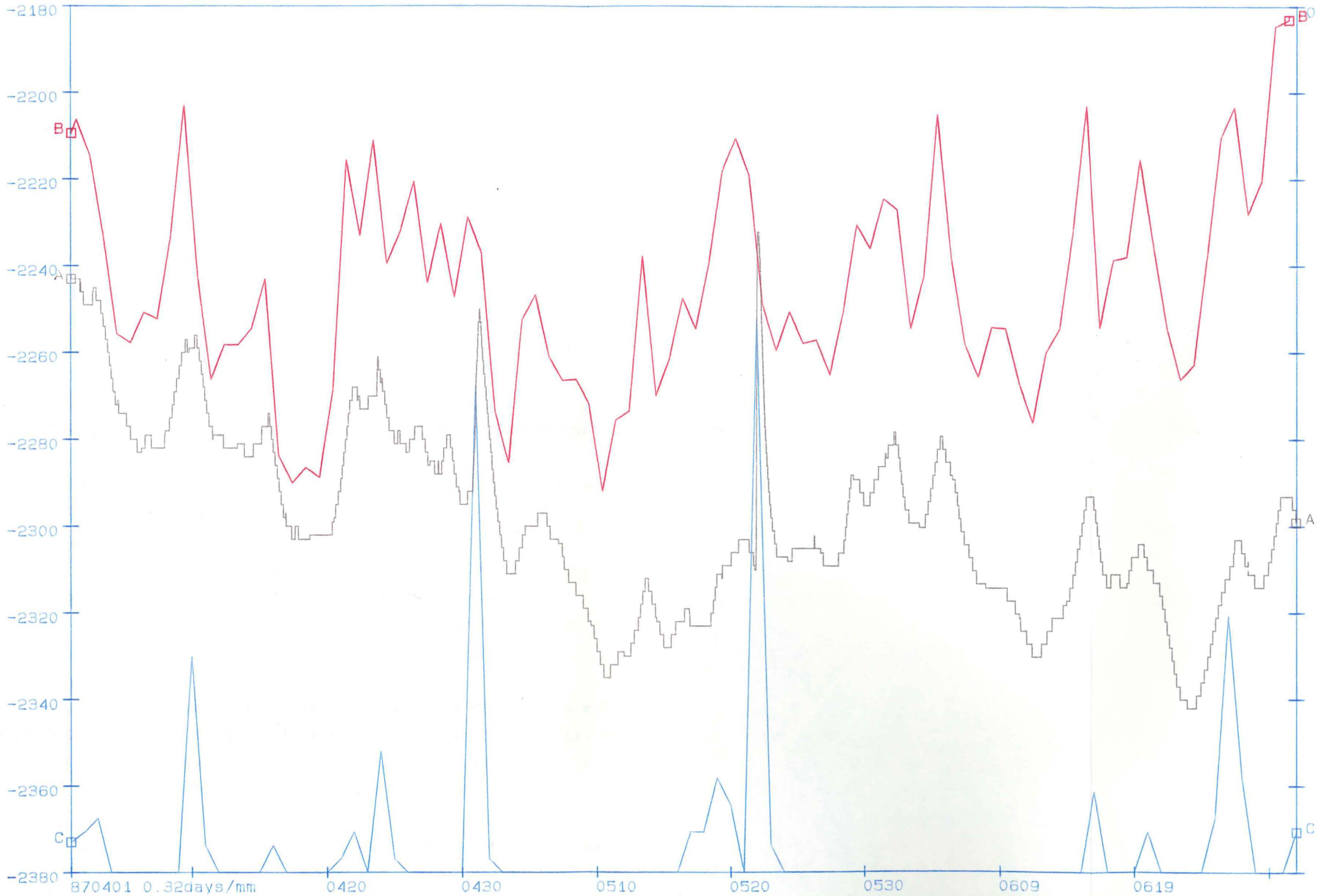
Flow lines were constructed for the August 1987 potentiometric map based on the same procedure used in the construction of the Spotswood flow map (Fig 4.13). The total Q recharging the aquifers of the Mina Plains from Mina and Crystal Brook Streams was 0.82 $m^3$/min. The total Q discharging from the aquifer was determined as 0.18 $m^3$/min (subsurface flow) and 2.00 $m^3$/min (estimated surface and artesian bore flow to the Jed River, see Appendix 4.4). The net difference of -1.36 $m^3$/min (or -23 $ls^{-1}$) is a reasonable indication of the hydrological equilibrium of the aquifer system.

4.5.5 Barometric Efficiency

Fluctuations of standing water levels in response to variations of atmospheric pressure measured at Kaikoura have been recorded at reference bore 033.8 located on the Mina plains. The barometric pressure/water level recorder/rainfall plot (Fig 4.15) shows an excellent response of groundwater levels to both rainfall and pressure, and the relation between barometric pressure and water levels is most apparent during periods of no rainfall. During these periods it is evident that as the barometric pressure fluctuates, there is a corresponding change in groundwater levels in boreholes that penetrate that aquifer. This is because at any level in the aquifer a change in water pressure implies a change in head, which in turn manifests itself as a change in water level in the well (Price 1985). Further, it is evident that the day to day change in water level within the aquifer is related to pressure fluctuations, and the week to week and month to month changes in water levels are related to rainfall.

An indication of how rigid an aquifer is can be obtained from the magnitude of the barometric fluctuation. A measure of how much increases in atmospheric pressure are borne by the aquifer framework and pore water respectively can be obtained by comparing the ratio of the change in water level in a borehole to the change in atmospheric pressure (equation 4.3). As atmospheric pressure is measured in millibars (or pascals) a conversion factor has to be applied to express the value in terms of head of a column of water (meters). One millibar is the equivalent of 100

Fig 4.15. Plot of Barometric Pressure recorded at site 2, Kaikoura (NZ Meteorological Service) versus water level at site N32.8 and rainfall (site 1234), Mina Plains




A: Tideda site 430008 1.units/mm Origin -2380
B: Tideda site 2 4.units/mm Origin -10700 Units=-file
C. Tideda site 1234 0.32units/mm

pascals and one pascal equals 1.019 x $10^{-4}$m $H_2o$ ($4^0c$). Thus;

the barometric efficiency $B = \frac{h}{p_a}$ Equation 4.3

where B is the barometric efficiency

is the specific weight of water

h is the change in piezometric level

$p_a$ is the change in atmospheric pressure.

Therefore the change in barometric pressure indicated by B in Fig 4.15, of 105.0mb equals 10500 pascals, and the corresponding water level change is 0.04m therefore;

$$B = \frac{0.04}{1.05m} = 0.0381 \times 100 = 4\%$$

A barometric efficiency of 4% is very low and is indicative of an unconsolidated, very weak aquifer (Price 1985).

## 4.6 Aquifer Performance

### 4.6.1 Methodology

The analytical methods applied in sections 4.6.2 to 4.6.4 are based on the following assumptions (after Todd 1980);

(i) The aquifer has a seemingly infinite areal extent.

(ii) The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by the pumping test.

(iii) Prior to pumping, the potentiometric surface is horizontal over the area influenced by the pumping test.

(iv) The aquifer is pumped at a constant discharge rate.

(v) The pumped well penetrates the entire aquifer and thus receives water from the entire thickness of the aquifer by horizontal flow.

As long there are only slight deviations from the above assumptions reasonable results can be obtained.

The practical importance of partial penetration is neglected due to the pronounced anisotropy of the alluvial aquifer, which results in reduced vertical flow components, thus enabling the pumping well to be approximated by a fully penetrating well in all pump tests.

This analysis of the performance of the pump tests closely followed the guidelines presented by Kruseman & Deridder (1970), Hazel (1975) and Clark (1977). The three comprehensive pump tests planned and performed during 1987 provided the first reliable quantitative information on the hydraulic characteristics on the aquifers in the Cheviot region, and were carried out as follows;

(1) on 21st June 1987 at the County Council Supply borehole, (reference N32.57) on the Spotswood Plains.

(2) on an agricultural supply borehole, (reference bore N32.19) on 20th August 1987.

(3) on borehole reference O33.74 on 21st October 1987 in the Mina area.

4.6.2 Pump Test 1 - N32.57

A constant discharge pump test was performed at bore 57 for 240 min at an average discharge rate of 1.2 $m^3$/min (Appendix 4.6). Drawdowns were observed at boreholes located 2.0 and 27.0 metres from the pumped borehole. A step drawdown test planned for this site was cancelled due to a malfunction of the pump on the day.

The time-drawdown curves for pump test 1 (Appendix 4.6) showed the aquifer was under unconfined conditions, and that flow to the well was in steady state for the duration of the pump test (steady state flow is a condition where variations of drawdown with respect to time are negligible).

Well discharge in an unconfined aquifer can be determined by the Theim Dupuit method (see Hazel 1975 for derivation);

$$Q = \frac{2\ T \times (s'_{m1} - s'_{m2})}{\ln \times (r_2/r_1)} \qquad \text{Equation 4.4}$$

where Q = well discharge in $m^3$/min

T = transmissivity $m^2$/min

$r_1$, $r_2$ are the respective distances of the piezometres from the pumped well in metres.

s′= the corrected drawdown in metres.

Equation 4.4 is identical to Theim's Equilibrium formulae (procedure 1) for a borehole in a confined aquifer;

$$Q = \frac{2 \times T \times (h_2 - h_1)}{\ln \times (r_2/r_1)} \qquad \text{Equation 4.5}$$

therefore

$$T = \frac{Q \quad \times \quad \ln r_2}{2 \quad \times (s_1 - s_2)\ r_1}$$

where $h_1$, $h_2$ are the respective elevations of the water levels in the piezometres in metres.

Thus given the data obtained during pump test 1 (Appendix 4.7), T = 4.56 $m^2$/min

Theim-Dupuit also proposed a second procedure similar to the first where a plot of $s_m$ versus r (Fig 4.16) is drawn on single log cycle paper. The slope of the best fit line is equal to $\Delta s_m$, the drawdown per log cycle of r, thus;

$$T = \frac{2.3 \times Q}{2 \times \Delta s_m} \qquad \text{Equation 4.6}$$

therefore T = 4.48 $m^2$/min.

The average coefficient of transmissivity for the aquifer at pump test site 1 is therefore 4.52 $m^2$/min.

4.6.3 Pump Test 2 - N32.19

(1) Constant discharge test

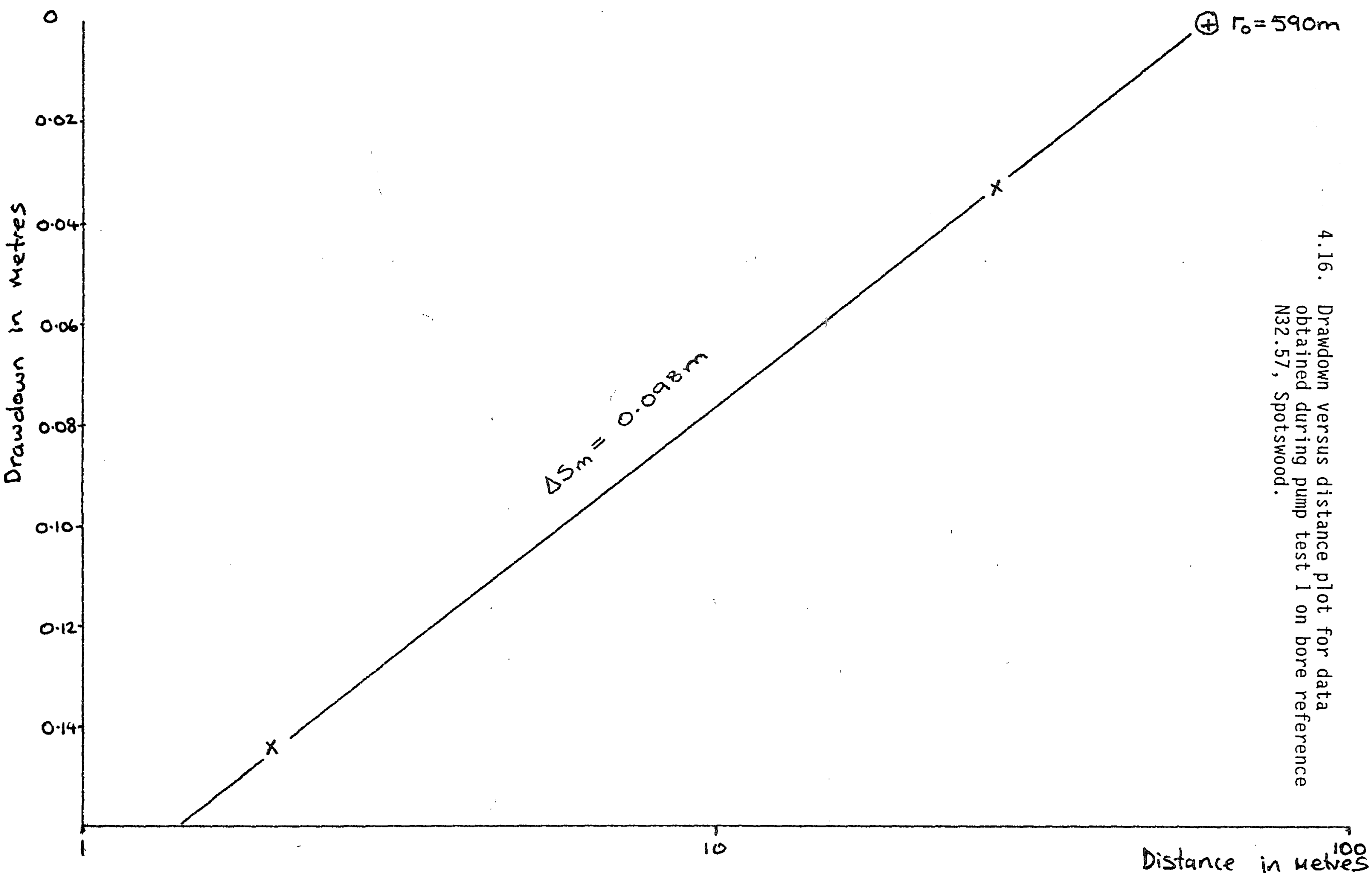
Pump site 2 was chosen in order to provide a quantitative comparison with the hydraulic characteristics obtained from the aquifer material at the County Council Supply well (reference N32.57). The borehole was in an ideal location within the discharge region of the Spotswood Plains, however the pump test site required the drilling of two piezometers as the nearest suitable piezometers were several hundred meters from the pumped bore. The time/drawdown curve shows that under pumping conditions of 0.78 $m^3$/min for 300 min the aquifer was under confined conditions, and flow to the borehole was in steady state (Appendix 4.7).

As for Pump Test 1 the numerical values of maximum drawdown measured in piezometres (Appendix 4.8) were substituted into equation 2, Theim's Equilibrium formulae, to give a value of T = 0.14 $m^2$/min.

A coefficient of T = 0.14 $m^2$/min at pump site 2 differed significantly to the T value of 4.52 $m^2$/min obtained from pump site 1. The interpretation of the disparity is that due to the anisotropic nature of the aquifer the No 2 piezometer of pump test 2 was located within a much finer material than the pumped bore. The results of the step drawdown test validate this conclusion (section (2) below).

(2) Step drawdown test

The analysis of the pumped borehole data obtained during a step drawdown test is based on Jacob's approximation that the drawdown in a pump-




4.16. Drawdown versus distance plot for data obtained during pump test 1 on bore reference N32.57, Spotswood.

ing bore is the sum of head losses in the aquifer (resistance to laminar flow) and head losses in the bore casing (resistance to turbulent flow in the zone adjacent to the borehole and through the screen).

The step drawdown relationship determined by Rorabaugh (1953) is given;

$$s = B \times Q + C \times Q^N \qquad \text{Equation 4.7}$$

where s = drawdown in the borehole (m)

B = coefficient in the laminar head loss

C = coefficient in the turbulent head loss

n = exponential coefficient in the turbulent head loss

assumed to be 2.

Q = discharge rate of borehole.

A step drawdown test involving four discharge steps of 0.42, 0.598, 0.618 and 0.723 $m^3$/min each of 55 min duration was performed on borehole 032.19 (Appendix 4.8, Fig 4.17). The planning of the test followed guidelines presented by Clark (1977).

Four analytical methods were applied to the pump test data to determine the functional coefficients B, C, and T.

(i) Jacob (1946)

Jacob developed the following general equation for the well loss factor C;

$$C = \frac{(\Delta s_w{}^{1}/\Delta Q^{1}) - (\Delta s_w{}^{i-1}/\Delta Q^{i-1})}{(\Delta Q^{i-1} + \Delta Q^{1})} \qquad \text{Equation 4.8}$$

The increments of drawdown ($s'_w$) were determined from a semilog scale plot of drawdown versus time, with time on the log axis. The incremental drawdowns and discharge rates from adjacent steps are substituted into the general equation to give a value for C of 6.06, (average).

(ii) Bierschenk and Wilson (1961)

Dividing equation 4.8 through by Q Bierschenk & Wilson obtained the expression;

$$sw/Q = B + C \times Q \qquad \text{Equation 4.9}$$

An arithmetic plot of specific drawdown ($s_w/Q$) against discharge (Appendix 4.8) provided a straight line with a slope of C and an intercept of B. The increments of drawdown were obtained using the same procedure as (i), and gave an intercept B of 2.1 and a slope C of 4.45.

*Fig 4.17. Step drawdown test curve for bore N32.19, pump test 2, Spotswood Plains*

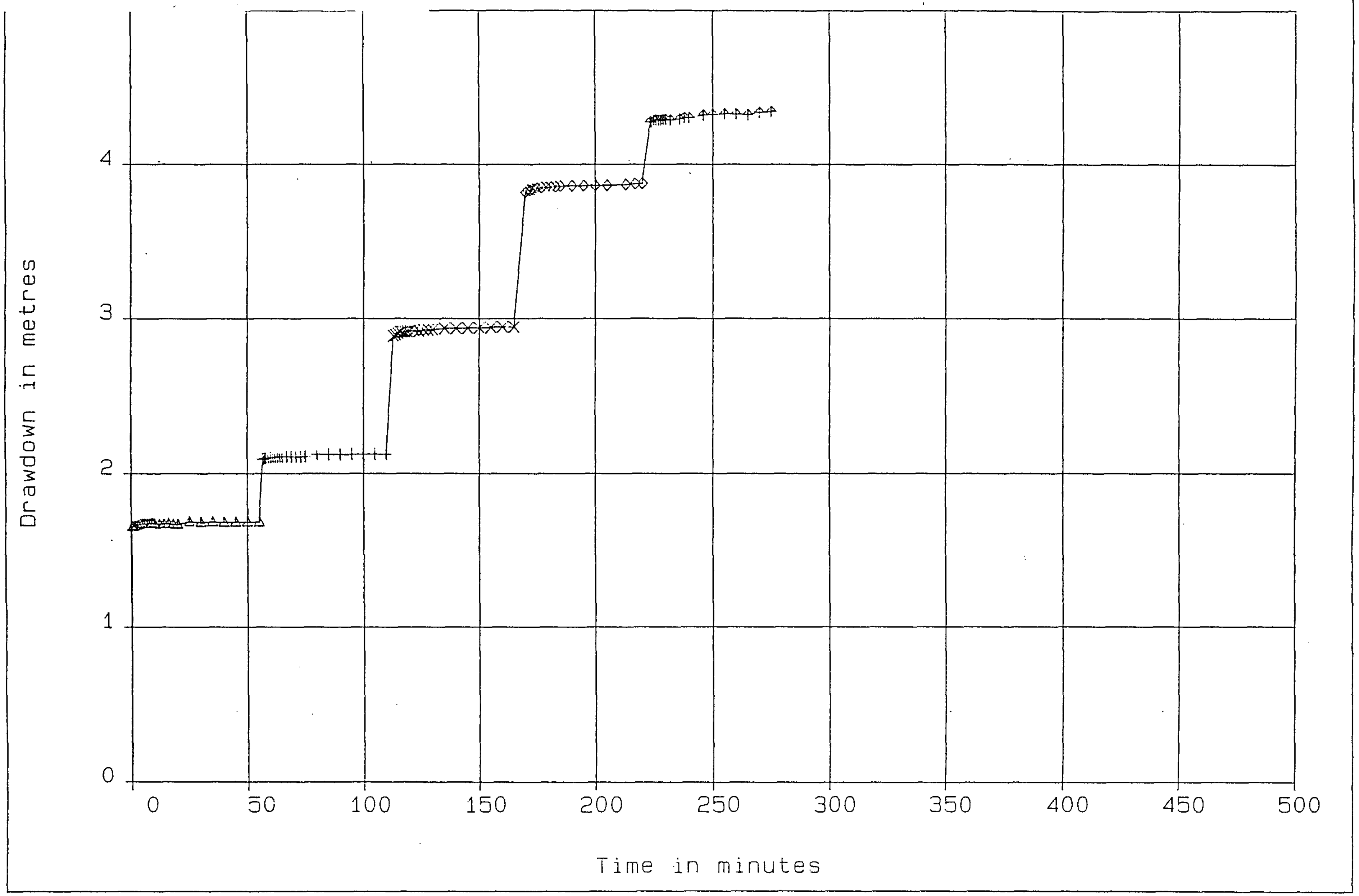



FIG 4.17

(iii) Hazel (1973)

The first step in this method is to construct the true drawdown - discharge rate curve for each step. Basically the procedure involves building up the true drawdown curve for each step using the incremental drawdown between successive steps (see Clark 1977 for further detail). Hazel uses this method to solve the equation (terms as defined in equation 4.7);

$$s_{wn} = (a + b \times \log t) \times Q_n + C \times Q_N^2 \qquad \text{Equation 4.10}$$

where $B = (a + b \times \log t)$

A value of b is obtained for each step from the relation ;

$$b = s_w/Q$$

Further, a plot of specific drawdown versus discharge rate will have a slope of C and an intercept of (a + b x log.t) (Appendix 4.8). The value of drawdown at unit time was taken from the time/drawdown plot (Appendix 4.8) and used to construct a specific drawdown versus discharge plot, then the intercept will be 'a' because (b x logt) will be zero (Clark 1977), thus;

$$b\ (\text{average}) = 0.398 \times 10^{-1}$$

$$C = 4.6$$

$$a = 1.75$$

As the true incremental for each step was determined a value of aquifer transmissivity was determined for each step, and the average value from the Hazel plot is $T = 4.49\ m^2/min$.

(iv) Eden & Hazel (1973)

The Eden & Hazel method of analyzing step drawdown tests is based on the equation;

and $$s_{wt} = a \times Q_n + b \times H + C \times Q_n^2 \qquad \text{Equation 4.11}$$

where $$H = \sum_{x=1}^{x=n} \Delta Q_x \times \log (t - t_x)$$

The procedure is tedious, involving the calculation of a value of H for each observation using measured values of discharge rate and time. Therefore a North Canterbury Catchment Board Step Drawdown programme was used to calculate H and $s_w$. The tables of values used in the computation are presented in Appendix 4.8 and the resultant equation of the best fit line is given by;

$$s = a \times Q + b \times H + C \times Q^2 + k \qquad \text{Equation 4.12}$$

thus $s_{wt} = -6.62 \times 10^{-1}.Q + 0.298 \times 10^{-1}.H + 0.615 \times 10^{1}.Q^2 + 0.628$
and $T = 0.613 \times 10^{1}\ m^2/min$

The values calculated for the equation of the best fit line predict that the suggested maximum drawdown of 5.87 m will occur at 20 weeks based on a calculated long term pumping rate of 0.916 $m^3/min$.

The negative 'a' parameter calculated in equation 4.12 indicates that the total drawdown losses are attributed to turbulence in the borehole and that there are no losses due to laminar flow in the aquifer, which is erroneous. The reason for the anomaly is not known.

The magnitude of the 'k' constant is a measure of the accuracy of the equation of the best fit line as it is added to the equation to improve the match of predicted drawdowns to actual drawdowns. As one of the principal aims is to obtain as close as possible approximation to the actual drawdown, the a, b and C parameters determined in Eden's analysis were substituted into equation 4.12 and a printout obtained (Appendix 4.9e). The result was that the k constant decreased from 0.628 to 0.09. The program calculated that the suggested maximum drawdown of 5.87 m will occur at 20 weeks based on a calculated long term pumping rate of 0.928 $m^3/min$ (Fig 4.18).

(3) Discussion

The analytical methods of Bierschenk & Wilson, Hazel and Eden & Hazel have given equations governing the drawdown - discharge relationship in borehole reference N32.19 (table 4.3) from which the main points are;

(i) Theoretical drawdowns determined by Bierschenk & Wilson and Hazel's methods at t = 240 min and Q = 0.78 $m^3/min$ are within 23 and 18 % respectively of the observed drawdown in the borehole. The theoretical drawdown determined by Hazel & Eden's equation is within 34 % due to the error introduced by a negative 'a' parameter.

(ii) The well loss element of the drawdown shows a spread of values from 2.71 to 3.74 m. The spread of values are the result of errors inherent in the methods.

(iii) The transmissivity values determined at the pumped borehole site are consistent for three out of the four analytical methods used and

Table 4.3 Summary Table of Results Obtained in Analysis of Pump Test #2

STEP DRAWDOWN TEST

| Analytical Method | Equation Governing drawdown in well | Theoretical Well loss at $Q=0.78m^3/min$ | Theoretical Drawdown after 240 min. at $Q = 0.78m^3/min$ | Transmissivity |
|---|---|---|---|---|
| Jacob | | 3.69 | – | – |
| Bierschenk & Wilson | $s_w = 2.1 \times Q + 4.45 \times Q^2$ | 2.71 | 4.35 | 0.581 |
| Hazel | $s_w = (1.75 + 0.398 \times 10^{-1} \log_{10} t) Q + 4.6 \times Q^2$ | 2.80 | 4.65 | 4.49 |
| Eden & Hazel | $s_w = (0.66 \times 10^{-1} + 0.298 \times 10^{-1} \log_{10} t) Q + 6.15 \times Q^2$ | 3.74 | 3.75 | 6.232 |
| CONSTANT DISCHARGE TEST | | | | |
| Theim | | – | 4.55 | 0.154 |

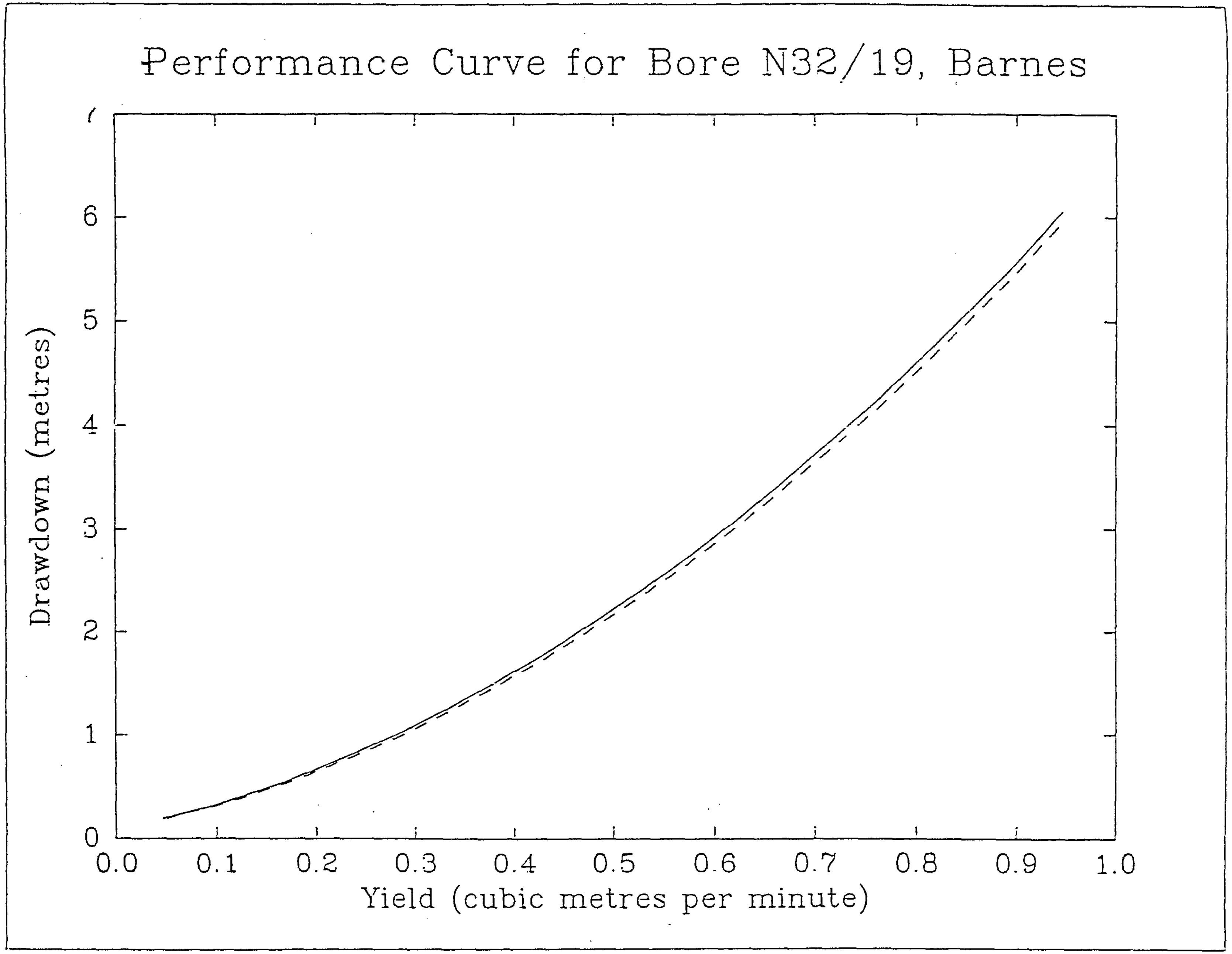

Performance Curve for Bore N32/19, Barnes
Drawdown (metres)
0
1
2
3
4
5
6
7
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Yield (cubic metres per minute)

FIG 4.18

range from 4.49 to 6.23 $m^2$/min. The Transmissivity value determined by Bierschenk & Wilson's method (0.581 $m^2$/min) is based on a erroneously high aquifer loss correction factor consequently it is significantly lower than the average value obtained by the other three methods. The Transmissivity value determined by the constant discharge test based on piezometric data is significantly less than the average determined at the pumped borehole site. This indicates that the piezometer is within a much finer material with a correspondingly lower hydraulic conductivity than the material at the pumped borehole site, and this is reflected in a lower Transmissivity value.

(iv) Values of S the Storativity were not determined due to the problem of identifying the effective radius of the pumped well.

(v) The results from Pump Test 2 emphasize the importance of applying several methods of analyses in any one test to safeguard against inaccuracies.

4.6.4 Pump Test 3 - 033.74

At a discharge rate of 0.076 $m^3$/min for 240 min the time drawdown curve (Appendix 4.9) shows that the aquifer was under confined conditions, and that flow to the well was in non - steady state.

(1) Theis Method.

The Theis curve matching method (Theis 1935) was used as a first approximation of Transmissivity and Storativity.

Theis's method is based on the assumptions listed in section 4.5.2 and that the water removed form storage is discharged instantaneously with decline of head and the diameter of the pumped well is very small.

The Theis Method involves preparing a type curve of W(u) against 1/u (reversed curve) over which a plot of drawdown versus time is placed. Once a best match fit is obtained between the data plot and the type curve an arbitrary match point is selected. To simplify calculations the matchpoint was selected when w(u) = 1 and 1/u = 10 (Appendix 4.9). The values of w(u), s (drawdown) and Q are substituted the equation;

$$T = \frac{Q \times w(u)}{4\pi \times s} \qquad \text{equation 4.13}$$

The data obtained from each of the piezometres are presented in Appendix 4.10b. The average transmissivity and storativity were calculated at T = 0.037 $m^2$/min and S = 2.12 x $10^{-3}$ respectively.

(2) Jacobs Method.

A second approximation of T and S were obtained by Jacob's method (Cooper and Jacob 1946). In addition to the assumptions of Theis method, Jacob's method is based on the presumption that values of u are small ($u = r^2 \times S / 4 \times T \times t < 0.01$).

A plot of drawdown versus the logarithm of time was drawn for each of the piezometres. A value for $t_0$ where drawdown is 0 and $\Delta s$ the drawdown difference per log cycle of time were determined from Appendix 4.9 and substituted the equations;

$$T = \frac{2.3 \times Q}{4\pi \times \Delta s} \qquad \text{equation 4.14}$$

$$S = \frac{2.25 \times T \times t_0}{r^2} \qquad \text{equation 4.15}$$

The average values of transmissivity and storativity for piezometres 1 and 3 are T = 0.04 and S = $6.6 \times 10^{-4}$.

The Theis recovery method was also used as it has the advantage over the constant discharge methods in that the rate of recharge Q is constant and equal to the mean rate of discharge Q during pumping. Based on the assumptions of the Jacob method the transmissivity is given the equation;

$$T = \frac{2.3 \times Q}{4\pi \times s''} \qquad \text{equation 4.16}$$

where $s''$ is the residual drawdown during the recovery period.

The residual drawdown per log cycle of $t/t''$ is read from a best fit line plot of $s''$ versus $t/t''$ on single logarithmic paper (Appendix 4.9).

The transmissivity values obtained from the three methods range from 0.035 $m^2$/min (Recovery data) to 0.037 $m^2$/min (Theis method) to 0.04 $m^2$/min (Jacobs method) averaging out at 0.038 $m^2$/min. All three methods approximate well which enhances the reliability of the results. The storativities do not significantly differ, ranging from $4.97 \times 10^{-4}$ to $6.6 \times 10^{-4}$.

The average T value obtained in Pump test 3 of 0.037 $m^2$/min is significantly less than the average T value obtained in Pump tests 1 and 2 of 4.52 and 5.36 $m^2$/min. It can therefore be concluded that the aquifer material at pump test sites 1 and 2 (Spotswood) is more permeable and thus will produce greater quantities of groudwater over a longer period than the aquifer material at pump test site 3 (Mina).

## 4.7 Hydrochemistry

### 4.7.1 Previous Studies

Previous chemical analyses of groundwater in the Cheviot region have been limited to three locations (North Canterbury Catchment Board unpublished data)

(1) Periodic analyses of samples of the Cheviot swimming pool from 1941 through to 1947 by employees of the Department of Health before the pool water was chlorinated. The samples were analyzed for $Cl^-$, $NO_3N^-$ and Total solids content only.

(2) Samples from shallow boreholes on the north and south side of the Waiau river in Spotswood during 1973 - 1982 as part of an investigative programme carried out by a consulting engineering company (Royds Gardner Co., Christchurch) which was responsible for determining a suitable site for a County Council supply well.

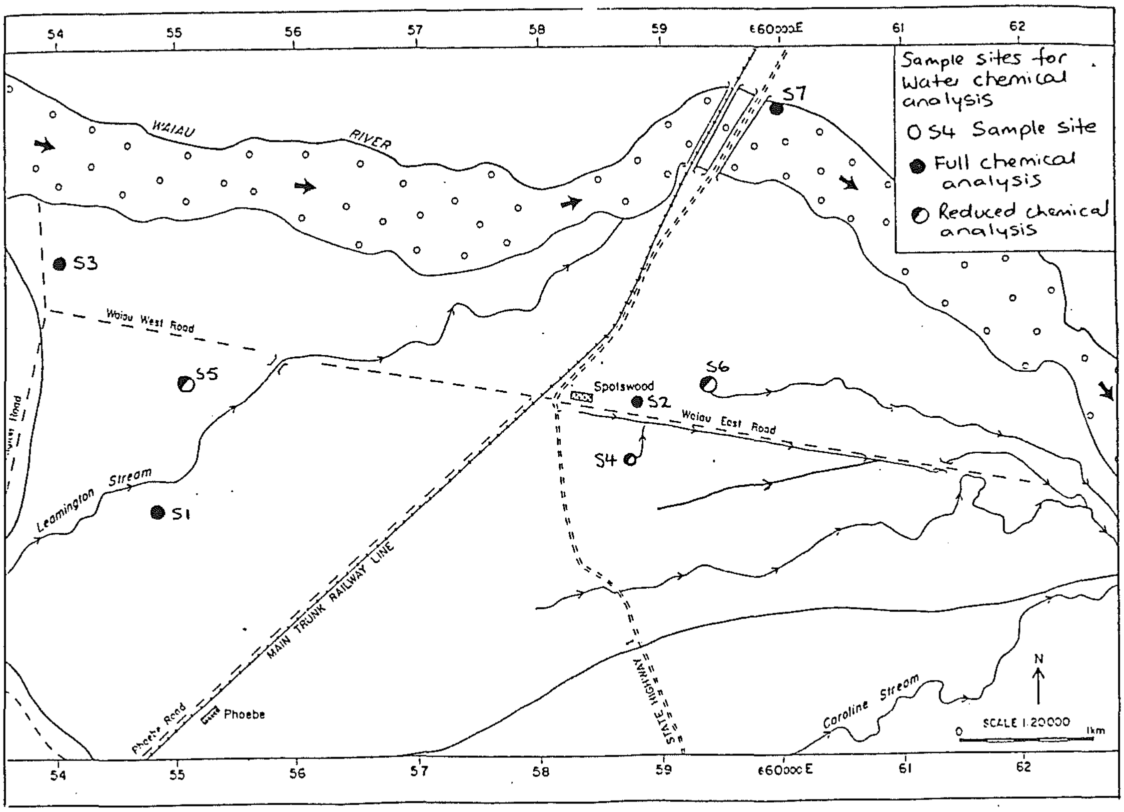
(3) A comprehensive chemical analysis of a domestic supply borehole in Mina carried out by Analytical Laboratories (Hastings).

### 4.7.2 Sampling and Analysis

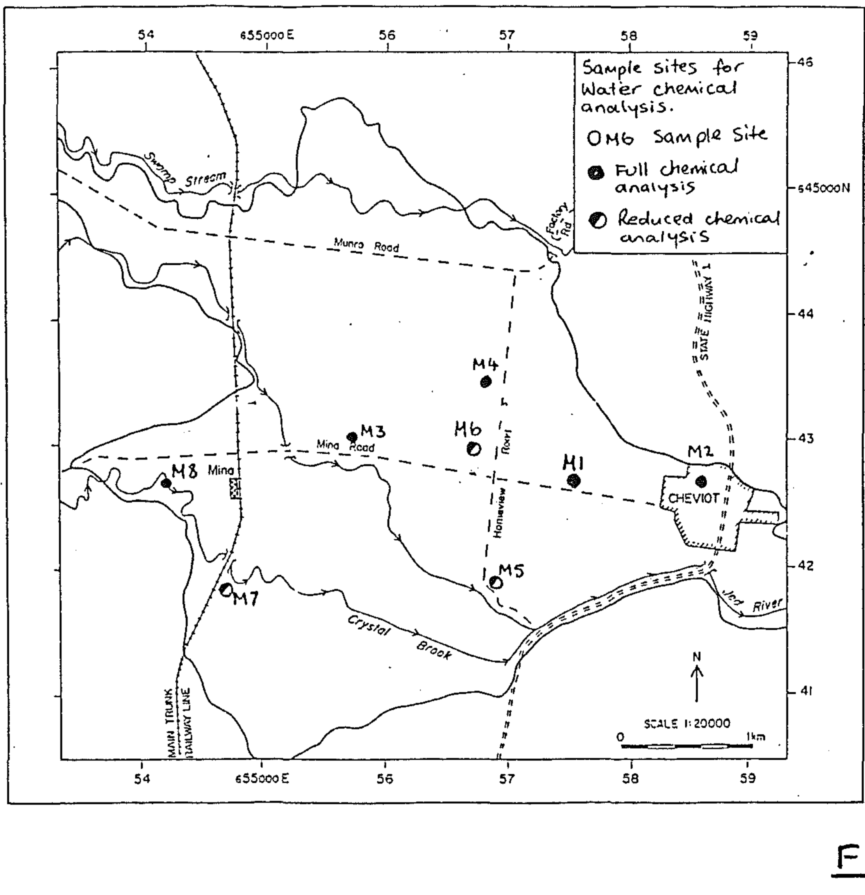
Although useful, the previous results are not comprehensive enough to establish whether or not the groundwater of the Plains in Spotswood and Mina are suitable as a potable and/or irrigation supply. Consequently a sampling programme was carried out using a trailer mounted pump and where possible domestic pumps by an employee of the North Canterbury Catchment Board and the writer on the 14th & 15th July 1987. The sampling procedure followed guidelines presented by Matthess (1982).

The sampling programme consisted of the collection of 18 samples from an equal number of boreholes in Mina and Spotswood areas of which 2 were samples of the Waiau River and Crystal Brook Stream tributaries. 8 of the 18 samples were analyzed for 13 major constituents and 6 for a reduced number of 4 constituents (Fig 4.19). A North Canterbury Catchment Board conductivity meter was used to analyze the remaining 4 samples for pH, temperature and conductivity. The results are summarized in table 4.4 and graphically presented in Fig 4.20.

Fig 4.19. Location diagram showing sample sites for water chemical analysis, Spotswood and Mina Plains



Sample sites for Water chemical analysis
O S4 Sample site
Full chemical analysis
Reduced chemical analysis
WAIAU RIVER
Waiau West Road
Waiau East Road
Leamington Stream
MAIN TRUNK RAILWAY LINE
STATE HIGHWAY
Spotswood
Phoebe
Phoebe Road
Caroline Stream
S1
S2
S3
S4
S5
S6
S7
SCALE 1:20000
660000E

Sample sites for Water chemical analysis.
O M6 Sample Site
Full chemical analysis
Reduced chemical analysis
Swamp Stream
Munro Road
Factory Rd
Mina Road
Mina
Honeyview Road
STATE HIGHWAY 1
CHEVIOT
Crystal Brook
Jed River
MAIN TRUNK RAILWAY LINE
M1
M2
M3
M4
M5
M6
M7
M8
SCALE 1:20000
655000E
545000N


FIG 4.19

Table 4.4 Summary Table – Chemical Analyses – Spotswood & Mina Plains

| Chemical Constituent mg/l | Sample Site S1 (N33.166) | S2 (O33.3) | S3 (N32.57) | S7 (Waiau) | M1 (O33.50) | M2 (O33.61) | M3 (O33.49) | M4 (O33.65) | M8 (Crystal Brook) |
|---|---|---|---|---|---|---|---|---|---|
| $NO_3^-N$ | 7.4 | 0.70 | 0.79 | 0.73 | 8.0 | 0.38 | 11.5 | 15.5 | 5.7 |
| $Na^+$ | 26.0 | 8.3 | 3.7 | 5.7 | 94.0 | 110.0 | 89.0 | 220.0 | 13.6 |
| $K^+$ | 2.5 | 0.81 | 0.66 | 2.2 | 1.0 | 2.8 | 3.9 | 6.8 | 4.2 |
| $Ca^{2+}$ | 42.0 | 19.0 | 12.0 | 11.0 | 38.0 | 96.0 | 30.0 | 54.0 | 18.0 |
| $Mg^{2+}$ | 16.0 | 3.3 | 1.5 | 2.4 | 19.0 | 17.0 | 15.0 | 27.0 | 4.6 |
| $SO_4^{2-}$ | 47.0 | 16.0 | 10.0 | 8.0 | 24.0 | 64.0 | 20.0 | 72.0 | 18.0 |
| $Cl^-$ | 20.0 | 6.0 | 3.0 | 6.0 | 246.0 | 140.0 | 140.0 | 300.0 | 20.0 |
| $HCO_3^-$ | 109.0 | 69.0 | 46.0 | 48.0 | 74.0 | 336.0 | 74.0 | 180.0 | 45.0 |
| $CO_3$ | 42.0 | 14.0 | 10.7 | 3.0 | 47.0 | – | 61.0 | 47.0 | 6.0 |
| $Fe^{3+}$ | 0.83 | <D.L | 0.13 | <D.L | 0.05 | 0.32 | <D.L | 0.17 | 26.0 |
| $SoO_2$ | 18.3 | 10.2 | 8.7 | 30.0 | – | 29.0 | 23.0 | 20.4 | – |
| $Mn^{2+}$ | <D.L | <D.L | <D.L | – | <D.L | 4.5 | <D.L | 0.24 | – |
| Total Hardness | 171 | 61 | 36 | 37 | 174 | 310 | 137 | 251 | 64 |
| Conductivity ($msm^{-1}$) | 42.0 | 17.1 | 10.7 | 11.9 | – | 102.9 | 71.2 | 153.0 | 17.9 |
| pH | 6.9 | 7.0 | 7.3 | 7.4 | 6.5 | 6.4 | 6.2 | 6.8 | 7.5 |

| Chemical Constituent mg/l | Sample Site S4 (O33.39) | S5 (N33.111) | S6 (O33.45) | M5 (O33.47) | M6 (O33.73) | M7 (N33.91) |
|---|---|---|---|---|---|---|
| $NO_3^-N$ | 0.87 | 1.06 | 0.66 | 4.5 | 14.0 | 4.5 |
| $Cl^-$ | 10.0 | 17.0 | 6.0 | 13.0 | 110.0 | 90.0 |
| $FE^{3+}$ | <D.L | 0.19 | 0.10 | <D.L | 0.47 | <D.L |
| $Mn^{2+}$ | <D.L | <D.L | <D.L | 0.39 | <D.L | <D.L |
| Cond | 22.5 | 36.8 | 14.3 | 79.2 | 64.3 | 65.7 |
| pH | 7.0 | 7.0 | 7.4 | 6.9 | 6.3 | 6.9 |

The samples can be grouped into two catorgories M and S, where samples S1 to S7 are from the Spotswood area and samples M1 to M7 are from the Mina area (Fig 4.19). Of the Spotswood samples S1, S2, S3 and S5 were taken from bores, samples S4 and S6 from springs (Willow and Awarnui) and sample S7 from the Waiau River. All of the Mina samples were taken from bores with the exception of M8, which was taken from Crystal Brook Stream.

Section 4.7.3 describes the results of samples analyses in terms of chemical constituents and their relation to the New Zealand Health Standard's 1984 guidelines for Drinking Water (Table 4.5), and also classifies the samples graphically (Davis and Dewiest 1967), based on equivalent percentage (meq%), cations are expressed as percentages of total cations in milliiequivalents/litre and anions are similarly expressed as percentages of total anions (fig 4.21).

4.7.3 Results of Analyses

(1) Spotswood

(i) Samples S2, S3 and S5: All three samples were taken from relatively shallow bores (less than 12 metres, see Appendix 2.1) located on the Spotswood Plains adjacent to the Waiau River.

The chemical analyses show that the water has low concentrations of the major cations and anions in terms of the guidelines suggested in Table 4.5, the low dissolved salt content is reflected in the conductivity readings which range from 10 to 36 $msm^{-1}$.

All three samples show that the groundwater has similar concentrations of all major constituents with the exception of sample S3 (County Council Supply bore) which contained 0.13 mg/l of $Fe^{3+}$, 0.03 mg/l above the recommended level set out in table 4.5.

The low concentrations are attributed to the Waiau River which recharges the aquifers of the Plains throughout the year thereby preventing the buildup of constitutents.

(ii) Sample S1: The chemical analysis of the groundwater from the 22 metre deep borehole N33.166 (Sample S1) is representative of the composition of groundwater beneath the higher terraces adjacent to Leamington Stream and beyond the recharge zone of the Waiau River. Although the concentrations of the majority of the major constituents are less than the

Fig 4.20. Chemical profiles of groundwater taken from bores in the aquifers of Mina and Spotswood Plains

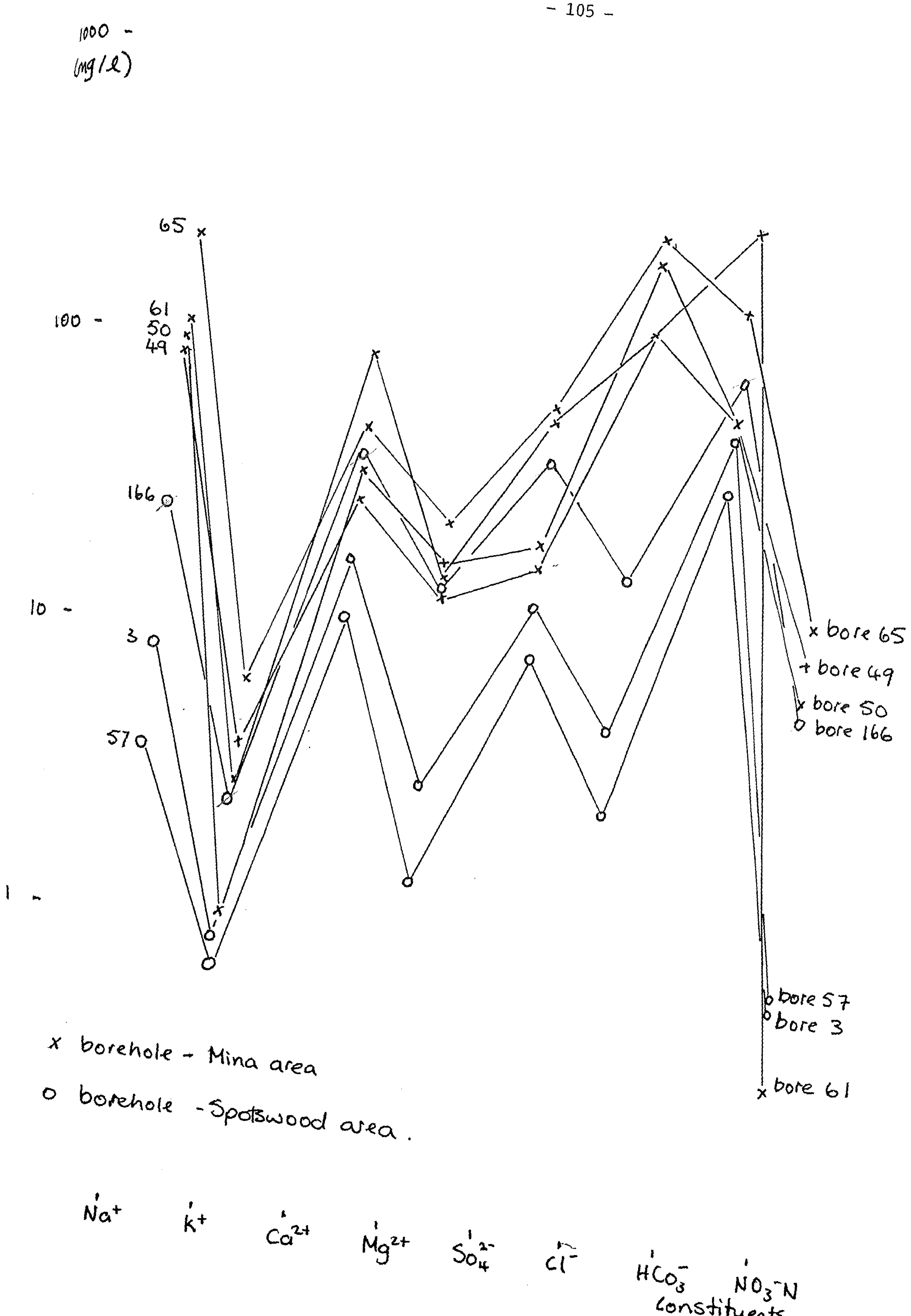

1000 -
(mg/l)
100 -
10 -
1 -
·1
65
61
50
49
166
3
57
x bore 65
+ bore 49
x bore 50
o bore 166
o bore 57
o bore 3
x bore 61
x borehole - Mina area
o borehole - Spotswood area.
Na+
K+
Ca2+
Mg2+
SO4 2-
Cl-
HCO3-
NO3-N
Constituents

Table 4.5 Summary Table - New Zealand Drinking Water Standards (1984)

| Chemical Constituent (mg/l) | Drinking Water Standards for New Zealand | |
|---|---|---|
| | Highest Desirable | Excessive |
| $NO_3^-N$ | 10 | |
| $Na^+$ | 100 | 200 |
| $SO_4^{2-}$ | 50 | 400 |
| $Cl^-$ | 100 | 250 |
| $Fe^{3+}$ | 0.1 | 1.0 |
| $Mn^{2+}$ | 0.05 | 0.5 |
| Total Hardness | 80 | 200 |
| pH | 7.4 to 8.5 | 7.0 to 8.5 |

highest desirable levels shown in table 4.5, they are consistently higher than the analyses of Samples S2 and S3 located on the Plains flanking the Waiau River.

The conductivity level of Sample S1 is 42 $msm^{-1}$, higher than either of Samples 1 to 3 suggesting a higher ionic content. The most noteworthy values in this analysis are the concentrations of $Ca^{2+}$ (42 mg/l), $Mg^{2+}$ (16.0 mg/l) and $SO_4$ (47 mg/l), which may combine to form the formation of an adherent, heat retarding scale on hot water systems. The increase in the concentration of $NO_3$-N from 0.70 mg/l in Sample S2 to 7.4 mg/l in Sample S1 suggests contamination of the groundwater by agricultural fertilizer. A further indication of contamination is the raised concentration of Bicarbonate ( $HCO_3^-$). Higher than desirable levels of $Fe^{3+}$ (0.83 mg/l) will, with the addition of atmospheric oxygen oxidize and precipitate as ferric hydroxide. Precipitates thus formed can cause turbidity, staining to plumbing fixtures, laundry and cooking utensils and imparts objectionable tastes and colours to foods and drinks.

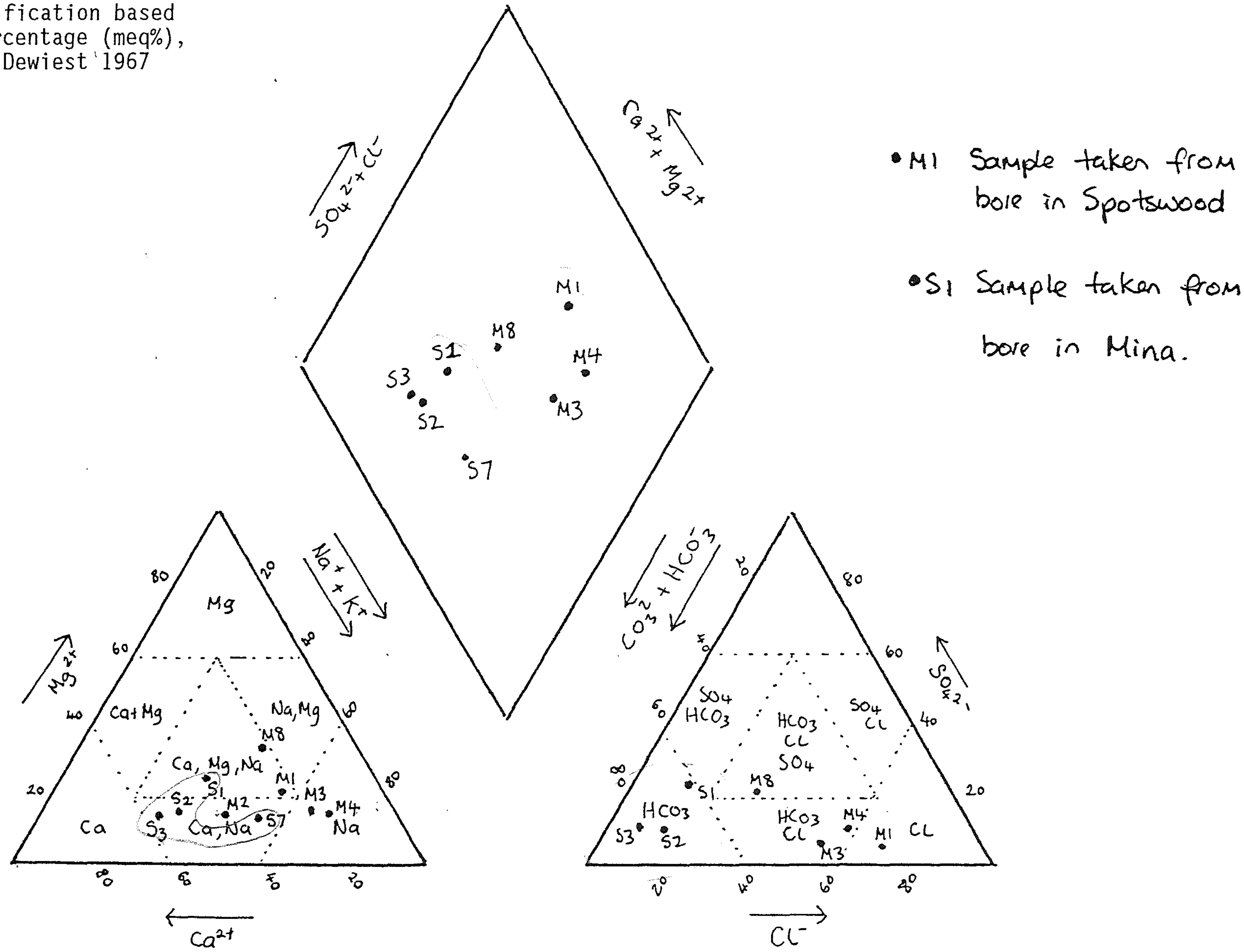
(iii) Samples S4 and S6: Water samples from the two most prominent springs in the Cheviot region region reference site 033.39 (Sample S4) and 033.45 (Sample S6) indicate that (as for bore Sample S2) the groundwater is of good quality and the concentrations of the major constituents are all within the desirable limits set out in table 4.5.

$NO_3$-N concentration levels of 0.87 mg/l and 0.67 mg/l for Samples S4 and S6 considerably lower than the highest recommended desirable levels of 10 mg/l. These low levels would normally indicate the absence of intensive fertilizer application or cultivation, but since this land has been cultivated for over 100 years, the low levels indicate that the rate of recharge of young water to the shallow aquifers in this area is sufficient to prevent the build up of undesirable levels of this and other major constitutents.

(2) Mina

Samples M1, M2 and M3: Observations made from the analysis of Samples M1, M2 and M3 taken from boreholes in the Mina Plains, show that the groundwater is generally of poorer quality in comparison to the groundwater of the Spotswood Plains within the desirable and excessive limits suggested in table 4.5. In particular the conductivity (71 to 153 $msm^{-1}$)

Fig 4.21. Classification based on equivalent percentage (meq%), after Davis & Dewiest 1967



and Total Hardness (137 to 251 mg/l) values of the Samples suggest high ionic contents, confirmed in the chemical analysis results.

The concentration levels of $NO_3$-N, $Cl^-$ and $Na^+$, particularly in Sample M2 are all significantly higher than the desirable levels suggested in table 4.5. The $NO_3$-N concentration of 15.5 mg/l in Sample M4 is 5.5 mg/l in excess of the highest desirable level of 10 mg/l in table 4.5 and may cause a health disorder known as Methaemaglobinanemia to which very young infants are especially susceptible. The concentrations of $Cl^-$ in Sample M1 of 246 mg/l and in Sample M2 of 300 mg/l are excessive in relation to the limit of 100 mg/l outlined in table 4.5. These levels of $Cl^-$ induce in groundwater a salty taste and may cause physiological damage to humans especially young children.

Sample M4: This sample was taken from a bore within the Cheviot town ship which is still used for irrigation of a household garden. The analysis showed a low concentration of $NO_3$-N namely 0.38 mg/l was in keeping with the location of the borehole, in the middle of the township where very little pastoral or agricultural activity has taken place over the years the borehole has been in operation. The water has a Total Hardness concentration of 310 mg/l as $CaCO_3$. The hardness of this groundwater is due to the presence of higher than desirable concentrations of $Ca^{2+}$ (96 mg/l) and $Mg^{2+}$ (17 mg/l). $Ca^{2+}$ and $Mg^{2+}$ at these concentrations will combine with bicarbonate, sulfate and silica to form heat retarding, pipe clogging scale in boilers and in other heat exchange equipment. A further consequence is that they will combine with ions of fatty acid in soaps; the more calcium and magnesium, the more soap required to form suds.

In addition Sample M2 has a $Fe^{3+}$ concentration three times the highest desirable level suggested in table 4.5. Concentrations of this proportion will with the addition of atmospheric oxygen oxidize and precipitate as ferric hydroxide. Precipitates thus formed can cause turbidity, staining to plumbing fixtures, laundry and cooking utensils and will impart an objectionable taste to foods and drinks. Excessively high concentrations of $HCO_3$ (336 mg/l) in this sample is an indicator of contamination of some nature. Concentrations of this magnitude have been proven to be not attributable to geologic origins (Matthess 1982).

Sample M : Exceptionally high concentrations of $NO_3$-N (5.7 mg/l) and $Fe^{3+}$ (26.0 mg/l) indicate the sample taken from Crystal Brook Stream was contaminated from non geologic sources such as old car bodies, placed along the stream bank in an attempt to control erosion. Consequently Sample M will not be considered further.

4.7.4 Tritium Results

Seven groundwater samples were collected and sent to Wellington for Tritium analysis (table 4.6).

The interpretation of the Tritium data is based on the assumption that flow characteristics of the groundwater in the Spotswood Plains adjacent to the Waiau River is predominantly plug - flow especially in preferred channels. The predominant flow characteristics in the Mina Plains is a mixture of plug flow and slow mixed flow.

The Tritium values for samples on the Spotswood Plains ranged from 4.53 (borehole reference 033.3) to 4.75 (borehole reference N32.57) which indicate the sample contained water either 32 years old or with a residence time of less than 5 years. In section 4.7.3 chemical analyses showed that the groundwater samples contained low concentrations of the major constituents. It can thus be concluded that the groundwater is considerably less than 5 years old.

Groundwater samples from Mina returned consistently lower Tritium values 3.29 (033.61) and 2.27 (033.49). This values indicate two possible ages as illustrated by fig 4.22, either 1958 - 63 or 1979 - 1985. Therefore a Tritium value of 3.3 could result from recharge within the last 5 years or from recharge that occurred about 22 years ago and has since decayed to a Tritium value of 3.3. The chemical analysis shows that this groundwater contains a high concentration of dissolved solids which indicate that the groundwater is more likely to be 20 years old than less than 5.

Table 4.6 Summary Table - Tritium Values Spotswood & Mina Plains

| | Sample Site | Tritium Value |
|---|---|---|
| 1 | (N33.166) | 3.81 ± 0.19 |
| 2 | (O33.3) | 4.53 ± 0.21 |
| 3 | (N32.57) | 4.75 ± 0.23 |
| 4 | (O33.61) | 3.29 ± 0.17 |
| 5 | (O33.49) | 2.27 ± 0.14 |
| 6 | (Waiau River) | 4.11 ± 0.20 |
| 7 | (Crystal Brook Stream) | 3.54 ± 0.19 |

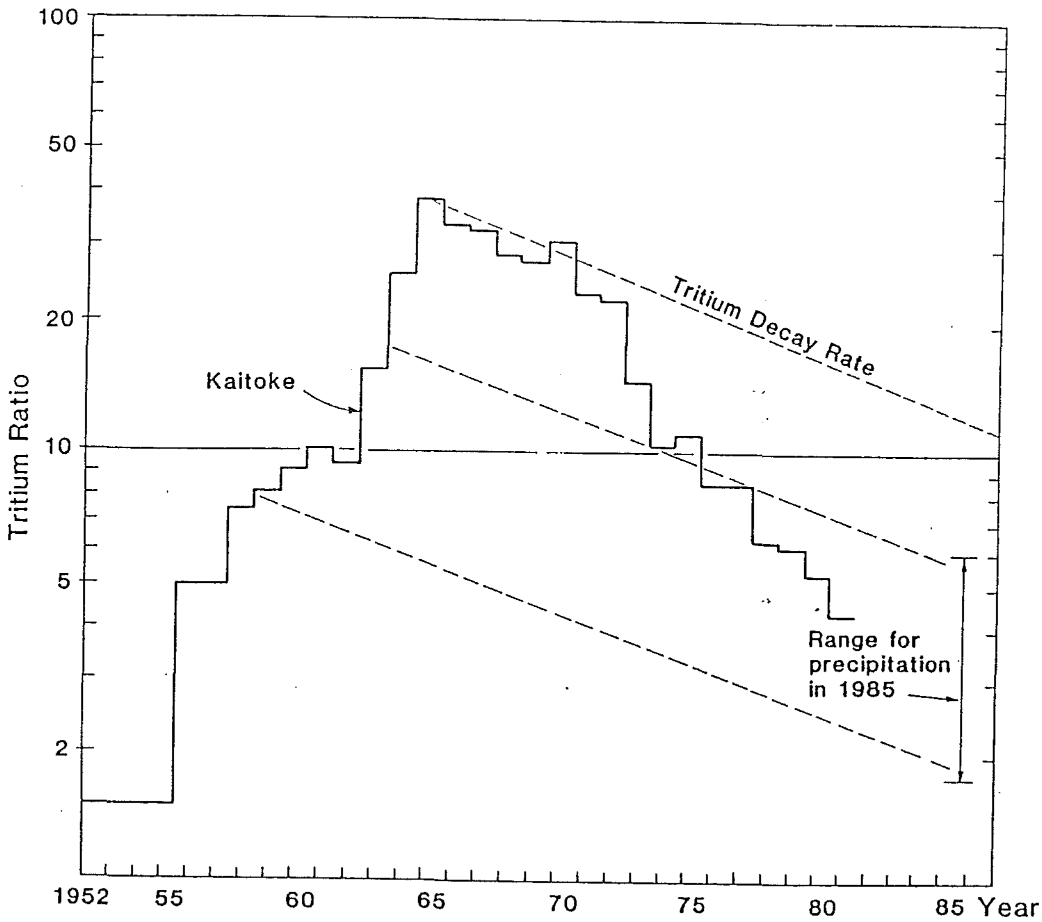



Fig 22: MEAN ANNUAL TRITIUM RATIO VALUES AT KAITOKE, NEAR WELLINGTON (41.1°S, 175.2°E)
(After Taylor and Stewart, 1981)

# 5.0 CONCLUSIONS

## 5.1 Geology

Geological investigations identified three main groups within the region; Mesozoic rocks, which form the basement and mountainous ranges of Cheviot Basin and consist of strongly indurated, graded bedded, poorly sorted quartzo-feldspathic sandstone and argillite with minor conglomerate and volcanics. The second group unconformably overlie the first forming the bedrock of the region and are of Tertiary age. Of the seventeen formations classified in this group by Browne & Field (1985), the Greta Formation is the most significant as it stratigraphically underlies the aquifer in the region and forms an effective aquiclude, it is described as a blue grey, moderately indurated, calcareous, bioturbated, micaceous, sandy mudstone. The third group are of Quaternary age and constitute the aquifer of the region. The group comprise of four units of fluviatile derived unconsolidated gravels, sands and silts each overlain by several metres of silty clay and form extensive terraced surfaces in the main plains areas of Spotswood and Mina.

The Quaternary materials were derived from Mesozoic and Tertiary lithologies mapped within the respective catchments. Erosion of the Mesozoic lithologies provided extremely durable rock fragments capable of surviving repeated episodes of transport and deposition and erosion of the Tertiary rocks produced the suspended load of transporting rivers and the matrix of gravel deposits rather than the clasts.

The Quaternary materials of Spotswood and Mina Plains differ in that the Spotswood materials were better sorted during transport and deposition The Mina Plains formed by two laterally coalescing fans built up by Crystal Brook and Swamp Streams and the resultant facies is poorly sorted due to torrential deposition and tends to become better sorted and finer grained away from the source outlets. The Spotswood Plains formed by extensive braided channels resulting in a complex aggradational association of channel lag deposits, overbank finer material and cross bedded and rippled sand bar material. Each successive period of aggradation was followed by a period of degradation in which loess (Aquitard) was deposited.

Based on the physical model proposed above the materials of the Spotswood Plains on an aquifer scale are better sorted than the comparative materials in the Mina Plains, especially in channel deposits which would exhibit higher permeabilities in part explaining the higher incidence of better yielding bores in Spotswood than in Mina.

## 5.2 Geophysical Investigations

Geophysical investigations were undertaken to assist in defining the thickness and to obtain a quantitative representation of the aquifer material in the absence of accurate material descriptions from bores in the region. Results obtained from two seismic refraction profiles carried out in the Cheviot region showed that the velocities of the unconsolidated gravels and the underlying siltstone are approximately 1100 and 990 $ms^{-1}$ respectively. As the strata's velocity does not increase with depth, the boundary contact between the two could not be detected and because of the velocity inversion no further profiles were surveyed.

Twenty eight resistivity soundings using the Schlumberger electrode array were conducted in the Cheviot region and three major geo-electric units identified. Unit 1 is identified as a clayey silt of relatively low resistivity, ranging from an average of 47 ohm-m and 4 metres thick in Mina and 40 ohm-m and 3 metres thick in Spotswood and is interpreted to be areally extensive in both the Spotswood and Mina Plains.

The second and more significant unit representing aquifer material differs markedly in resistivity and thickness throughout the region. It is made up of poorly to well sorted gravels within a matrix ranging from silty clay to sand. At Mina this unit has relatively low resistivities (average 140 ohm-m) in comparison to the equivalent unit at Spotswood (average 422 ohm-m), indicating the aquifer material overall has a higher proportion of fine grained material both within the matrix and as distinct layers and will generally be less permeable, later proven by pump tests. The average thickness of the aquifer material in Mina is approximately 10 metres and although it is reasonably uniform in thickness it does appear to progressively thin towards the south east, reflecting two coalescing alluvial fans. At Spotswood the aquifer material thickness increases progressively from 20 metres, in a north easterly direction towards the Waiau river at which point it is estimated that the total thickness is approximately 70 metres. The third unit differs markedly in average resistivity to the overlying second unit. In Mina the third unit has an average resistivity value of 22 ohm-m and in Spotswood an average resistivity value of 31 ohm-m, indicative of a massive silty mudstone, and represents bedrock (Aquiclude).

On an aquifer scale interpreted geoelectric sections correlated well with known material description logs obtained from a number of bores in Spotswood and Mina. Generally the interpreted thickness the three geoelectric units and depths to bedrock were within 20-30% of actual values obtained from drilling and bore material descriptions.

The resistivity soundings failed to detect much of the fine layering known to be present within the aquifer section. At two sites in particular, relatively thin yet extensive clay and gravel layers within a gravel section and clay section respectively were not detected because their effective thickness was not sufficient in relation to surrounding layers.

Conductivity analyses of groundwater samples support earlier assumptions that matrix conduction and not pore water conduction is the dominant conduction mechanism in gravel sections for both areas. Higher conductance values were obtained from boreholes in Mina than in Spotswood indicating that the porewater has a higher dissolved salt content.

Several attempts were made at obtaining a relation between resistivity and effective porosity, using the Formation Factor and porewater resistivities. However no correlation could be determined due principally to the influence of varying amounts of matrix conduction on the conduction process at sounding sites throughout the plains areas. It would appear that the most reliable indicator of relative permeability in material influenced by matrix conduction, is the measured total resistivity whereby higher resistivities indicate higher effective porosities.

Estimates of porosity, density and clay content were obtained from a nuclear logging programme carried out on four boreholes in the region. Unit two, the aquifer was the main target of interest. Although average total porosities were similar for this unit in both the Spotswood (26%) and Mina (24%) areas the higher clay content indicated by the natural gamma log and the higher densities given by the gamma gamma log suggest that the effective porosity of the aquifer in Spotswood is significantly greater than the aquifer in Mina.

### 5.3 Hydrological Investigations

Within Spotswood the major contributors to the aquifer system are the Waiau River and Leamington Stream. Unfortunately Waiau River was only gauged at one location therefore estimates of river losses could only be obtained from flow nets. Leamington Stream discharges approximately 213 $ls^{-1}$ to the aquifer system of the lower Plains near the Waiau West Road bridge and in Mina, Crystal Brook and Mina Streams discharge on average 44 $ls^{-1}$ to the aquifer system near borehole reference N33.8.

Potentiometric surveys indicated that recharge from the Waiau River was continuous throughout the year, whilst recharge from Leamington Stream was intermittent occurring only in the Winter months. Similar surveys for the Mina area showed that recharge from the two main streams in the area occurred only in Winter. The general pattern is one of steadily declining water levels from December to February, reflecting the summer recession of the Waiau River and other streams and recovery from April due to recharge from the higher winter flows. Water level records from bores near the Waiau River indicate that the aquifer of the lower Spotswood Plains adjacent to the Waiau River are effectively a subsurface flow extension of the waters of the Waiau River.

A rainfall source of recharge is also shown by the good correlation between rainfall and the fluctuations superimposed on the aquifer hydrograph. The rapid rise with rainfall confirms the aquifer within the Spotswood and Mina area are affected by atmospheric pressure.

Flow nets showed that the total recharge flow to the aquifer system on the Spotswood Plains from the Waiau River and the Leamington Stream was 47.0 $m^3$/min at the time the survey was carried out on $14^{th}$ August 1987. The total discharge from the aquifer system was determined as 47.0 $m^3$/min, comprising of subsurface flow (29.0 $m^3$/min) and surface flow from artesian bores and springs (18.0 $m^3$/min). Flow nets also constructed for the Mina Plains showed that the total recharge flow for the Mina Plains aquifer system for $14^{th}$ August 1987 was 0.8 $m^3$/min and total discharge was estimated at 2.0 $m^3$/min.

Two pump tests were carried out in the aquifer system of the lower Spotswood Plains to provide quantitative data on the hydraulic characteristics of the aquifer. Pump tests 1 and 2 were carried out in the upper (unconfined) and lower (confined) portion of the plains respectively. The pump tests gave average transmissivities (4.52 $m^2$/min and 5.36 $m^2$/min respectively) that are typical of unconsolidated sandy gravel aquifers elsewhere in northern Canterbury. The third pump test was carried out on a recently drilled bore which (considered to be an excellent groundwater producer for the Mina area), in the lower portion of the Mina Plains under confined hydraulic conditions. The calculated average transmissivity (0.038 $m^2$/min) and storativity (5.4 x $10^{-4}$) values were significantly less than those determined in Spotswood and reflected the higher fines content and lower permeability of the Mina aquifer system.

## 5.4 Water Quality

The Chemical analyses of the groundwater from the Mina area showed that it was of poor quality with respect to the New Zealand Health Standards (1984) and has a residence time of greater than twenty five years.

Furthermore analyses showed concentrations of major cations were consistently higher than the desirable levels suggested by the New Zealand Health Standards for Drinking Water (1984), for example $NO_{3-N}$ (average 12.0 mg/l), Cl (average 180 mg/l) and Na (average 90 mg/l). Several bores (in particular bore reference 033.65) showed concentrations of the major constituents ($NO^3$-N of 15.5 mg/l, Cl of 300 mg/l and $Na^{3+}$ of 220 mg/l) which indicated non geological source, most probably contamination from offal holes. Consequently the use of groundwater in the Mina area for domestic supply' if untreated, would result in staining of hot water cylinders, cooking utensils and impart an objectionable taste to food and drinks.

In contrast the chemical analyses of samples taken from bores in Spotswood particularly on the lower plains adjacent to the Waiau River showed that the water is less than five years old with concentrations of all major cations and anions below the Drinking water standards. The excellent quality of the water is due to dilution effect from recharge waters of Waiau River and Leamington Stream which have prevented the build up of constituents in the groundwater.

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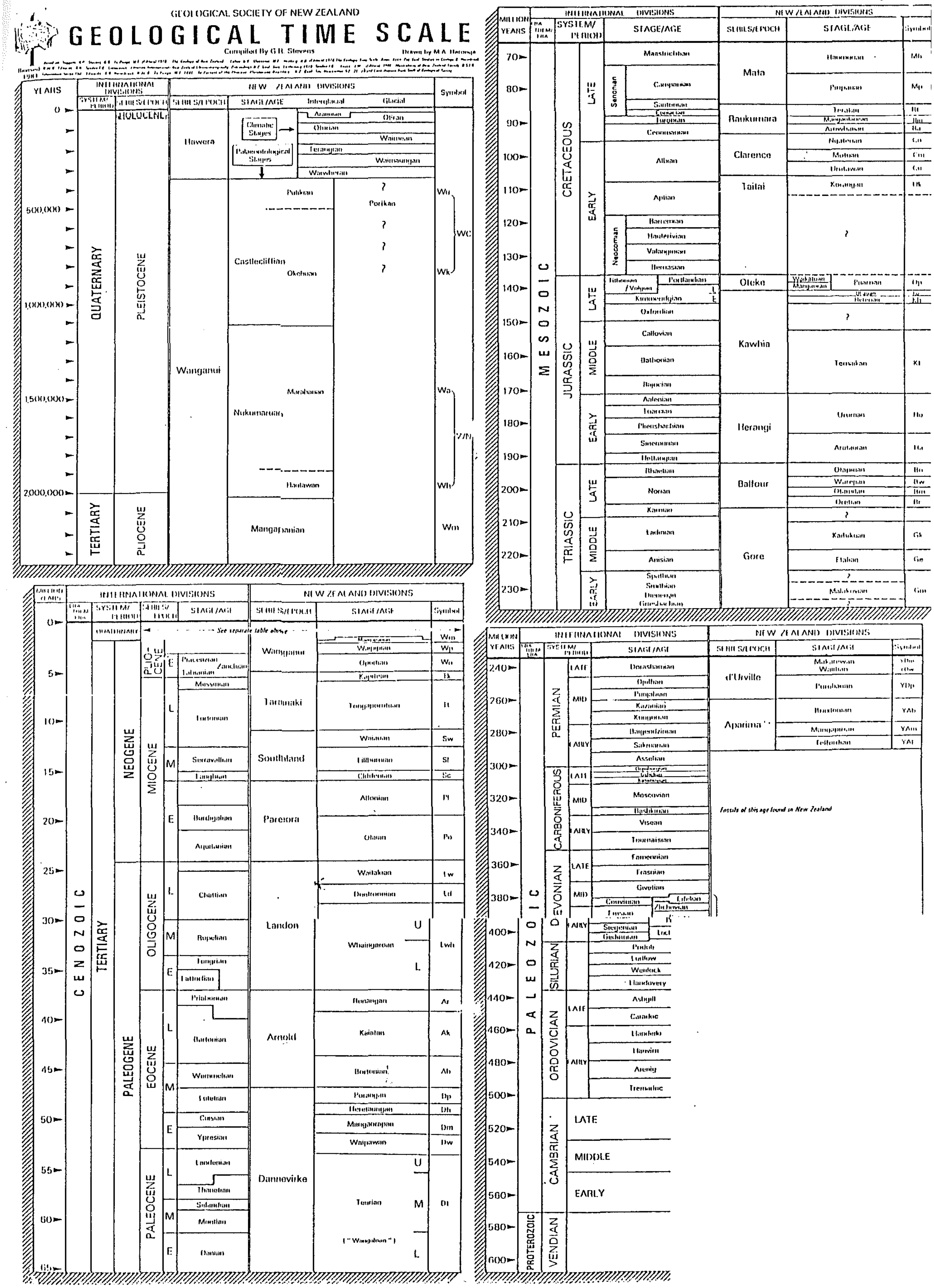
4.7 Data and drawdown curves obtained from constant discharge pump test carried out on bore N32.19 in Spotswood.

4.8 Data and drawdown curve obtained from step drawdown test carried out on bore N32.19 in Spotswood.

4.9 Data and drawdown curves obtained from constant discharge pump test carried out on bore 033.74 in Mina.




APPENDIX 2.1 - Geological time scale

# APPENDIX 2.2 - Material description logs from bores in Spotswood area

## LOG OF BOREHOLE

AREA: SPOTSWOOD
GRID REF: 541 524
BOREHOLE No: Council well
DATUM (m): ≈ 44.3 a.m.s.l
DRILLER: M.O.W.D chch
SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS |
|---|---|---|---|---|
| 0 | surface soil | | unweathered, moist, soft, dark brown, massive, silt with some clay (OH) | |
| 1 | clayey SILT | | unweathered, dry, hard, light olive brown, massive, clayey silt with some sand (ML) | |
| 4–8 | sandy GRAVEL with some silt | | slightly weathered, moist from 2.8→7.5m and saturated from 7.5→to end of bore, compact, very coarsely layered, moderately well sorted, well to very well rounded clasts of predominantly greywacke from <1cm up to 14cm in length occasional crystalline rock clasts, sandy gravel with some silt. (GP) | |
| 12 | silty SANDS | | slightly weathered, moist, compact, light yellowish brown, massive, silty sand (SM) | |
| 14–17 | sandy GRAVELS | | slightly weathered, saturated, compact very coarsely layered, moderately well sorted, well to very well rounded clasts (pred. greywacke) occasionally crystalline rock clasts up to 10cm on average 7cm, sandy gravel with some silt (GP) | |
| 18 | end of bore at 17.6m | | | |

## LOG OF BOREHOLE

AREA: SPOTSWOOD
GRID REF: 540 530
BOREHOLE No: M32.56
DATUM (m): ≈ 44.3 a.m.s.l
DRILLER: Bisley
SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS (Yield 1800 m³/day; Specific cap 3913 m³/day) |
|---|---|---|---|---|
| 0 | SILT | | | |
| 3 | GRAVEL & SAND | | | |
| 8 | GRAVEL | | cemented sand & gravel | |
| 10 | GRAVEL | | Tight big gravel, sand and some clay | |
| 12 | | | big to small gravel and sand | |
| 14 | | | | |

## LOG OF BOREHOLE

AREA: SPOTSWOOD
GRID REF: 539 517
BOREHOLE No: 032.19
DATUM (m): 30.8 a.m.s.l
DRILLER: McLean (1964)
SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS (Yield 1635 m³/day; Specific cap 2.06 m³/day) |
|---|---|---|---|---|
| 0 | Soil & silt | | | |
| 2 | Clayey SILT | | No Description recorded | |
| 5 | GRAVELS | | Interbedded silty and sandy GRAVELS | water bearing |
| 7 | silty CLAY | | | |
| 8 | GRAVELS | | | Confining |
| 10 | Sandy GRAVELS | | | |
| 13 | END OF BORE AT 12.64 | | | |

## LOG OF BOREHOLE

AREA: SPOTSWOOD
GRID REF: 540 514
BOREHOLE No: 032.17
DATUM (m): 29.5 a.m.s.l
DRILLER: Cashmere
SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS (Yield 864 m³/day) |
|---|---|---|---|---|
| 0 | Surface SOIL | | Dark brown | |
| 1 | CLAY | | Yellowish | |
| 3 | GRAVEL | | Sand and shingle with boulders up to 15cm, clasts greywacke. | |
| 5 | End of bore at 4.6m | | | |

## LOG OF BOREHOLE

…TSWOOD
…O: 032.16
BISLEY & Co

GRID REF:: 584 516
DATUM (m): a.m.s.l
SCALE:

| L | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS |
|---|---|---|---|
| L | | | Specific cap 3.4 l/s/m<br>Yield 300 $m^3$/day |
| | | grey-brown gravel with some silt and sand | |
| | | grey-brown clay | |
| | | grey brown clay & silt | |
| | | Small to medium green grey sand & grit, clasts becoming larger with depth | |

## LOG OF BOREHOLE

AREA: PHOEBE
BOREHOLE No: N33.86
DRILLER: McLean

GRID REF:: 550 492
DATUM (m): 59.0 a.m.s.l
SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS |
|---|---|---|---|---|
| 0–2 | brown CLAY | | | |
| 2–12 | SHINGLE | | | |
| 12–13 | sandy GRAVEL | | sandy Gravels with some clay. | FAILED WELL<br>No Appreciable Water. |
| 13–14 | CLAY | | | |
| 14–22 | GRAVEL | | | |
| 22–23 | CLAY | | | |
| 23–30.4 | CLAY & GRAVEL | | clay shingle and gravel | |
| 30.4 | END OF BORE AT 30.4m | | | |

Depth scale: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30

# APPENDIX 2.3 - Material description logs from bores in Mina area

## LOG OF BOREHOLE

Incomplete

AREA: MINA # 1
GRID REF:
BOREHOLE No: 1133·176
DATUM (m): a.m.s.l
DRILLER: MACMILLAN (12-8-87)
SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS (Approx yield, litres/min m³/day; Specific cap. litres/min/metre m³/day) |
|---|---|---|---|---|
| 0 | Surface SOILS | | unweathered, moist, soft, dark brown massive, silt with some clay, (OH) | |
| 1–2 | clayey SILT | | unweathered, dry, hard, light olive brown, massive, clayey silt with some sand, (ML) | Relatively impermeable |
| 3–6 | clayey GRAVELS with some silt | | slightly weathered, saturated, compact, light yellowish brown, very coarsely layered, poorly sorted, well rounded, clayey coarse gravel with some sand, predominately greywacke clasts from 1cm — 13cm average 6cm, (GC) | poor permeability |
| 7–8 | | | | |
| 9–10 | clayey SILT | | slightly weathered, saturated, hard, light brown, massive, clayey silt with some gravel, (ML) | |
| 11–12 | clayey GRAVELS with some silt | | slightly weathered, saturated, compact, light brown, very coarsely layered clayey coarse gravel with some sand, pred greywacke clasts 1cm–11cm, occ crystalline rock clasts 3-4cm (GC) | |
| 13–15 | silty GRAVEL with some sand | | slightly weathered saturated/compact, dark bluish grey, coarsely layered silty coarse gravel with some clay pred unweathered greywacke clasts from < 1cm — 6cm. (GM) | |
| 16 | silty MUD<br>End of bore | // | unweathered, moderately strong, dark bluish grey, massive, mudstone. (E) | |

## LOG OF BOREHOLE

AREA: MINA # 2
GRID REF:
BOREHOLE No: 1133·177
DATUM (m): 83·8 a.m.s.l
DRILLER: MACMILLAN
SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS (Approx yield litres/min m³/day; Specific capacity litres/min/metre m³/day) |
|---|---|---|---|---|
| 0 | surface SOILS | | unweathered, moist, soft, dark brown, massive, silt with some clay (OH) | |
| 1–2 | clayey SILT | | unweathered, dry, hard, light olive brown massive, clayey silt with some sand, (ML) | |
| 3–5 | clayey GRAVEL with some silt | | slightly weathered, moist, compact, light yellowish brown, very coarsely layered, poorly sorted, well rounded, clayey coarse gravel, predominately sl weathered greywacke clasts from <1cm —10cm, average 5cm (GC) | |
| 6–7 | silty GRAVELS with some clay | | slightly weathered, saturated, compact, light brown, very coarsely layered, poorly sorted, silty coarse gravel with some clay, pred sl weathered greywacke on average 7-9cm, occ crystalline rock clasts. (GM) | |
| 8 | silty SAND | | weathered, moist, compact, light yellowish brown, massive, silty sand (SM) | |
| 9–11 | clayey GRAVEL with some silt | | slightly weathered, saturated, compact, light yellowish brown, very coarsely layered, poorly sorted, well rounded, clayey coarse gravel (GC) | |
| 12 | silty MUD<br>End of bore | // | unweathered, moderately strong, dark bluish grey, massive, Mudstone (E | |
| 13 | | | | |

## LOG OF BOREHOLE

AREA: MINA # 2.
GRID REF:
BOREHOLE No: 033·74
DATUM (m): 59·4 a.m.s.l
DRILLER: MacMILLAN
SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS |
|---|---|---|---|---|
| 0 | Surface SOILS | | unweathered, moist, soft, dark brown, massive, silt with some clay (OH) | |
| 1–3 | clayey SILT | | unweathered, moist, hard, yellow brown, massive, slightly mottled, clayey silt with some sand. (ML) | |
| 4–5 | sandy GRAVEL with some silt | | slightly weathered, saturated, compact, light yellowish brown, coarsely layered, moderately well sorted, well rounded, coarse sandy gravel with some silt, greywacke clasts <1cm – 6cm average 4cm, (GM) | EXCELLENT. |
| | clayey SILT | | see A/A | |
| 6 | clayey GRAVEL with some silt<br>end of bore @ 6·3m | // | slightly weathered, moist, compact, light yellowish brown, very coarsely layered, poorly sorted, well rounded clayey coarse gravel (GC) | |

## LOG OF BOREHOLE

AREA: MINA
GRID REF: 557 429.
BOREHOLE No: 033·48
DATUM (m): 66·2. a.m.s.l
DRILLER: D Davies.
SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS |
|---|---|---|---|---|
| 0–3 | Sandy CLAY | | no description recorded | |
| 4 | shingle | | | |
| 5–6 | clay | | | |
| 7–8 | Shingle | | no description recorded. | |
| 9 | papa<br>end of bore @ 9·1m. | | | |

## LOG OF BOREHOLE

AREA: CHEVIOT | GRID REF: 588 424
BOREHOLE No: 033 20 | DATUM (m): 62.5 a.m.s.l
DRILLER: McLean Engineering (1964) | SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS |
|---|---|---|---|---|
| 0 | surface CLAYS | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | CLAYS | | brown clays | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | fine greywacke gravels | Well pumped continuously for one week at 38.2 m³/day |
| 10 | GRAVELS | | | |
| 11 | clay & gravel | | brown clay & fine gravel | |
| 12 | GRAVEL | | greywacke gravel. | |
| 13 | clay & gravel | | brown clay & fine gravel. | |
| 14 | | | | |

## LOG OF BOREHOLE

AREA: CHEVIOT | GRID REF: 571 · 442
BOREHOLE No: 033·10 | DATUM (m): a.m.s.l
DRILLER: Job Osborne (1898) | SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS |
|---|---|---|---|---|
| 0 | | | Surface soil and clay<br>shingle<br>papa<br>shingle and conglomerate<br>papa<br>some shingle | |
| 10 | | | | a little water in it but will not rise |
| 20 | | | | |
| 30 | | | | |
| 40 | | | | |
| 50 | | | Papa, occasionally slaty with some sand, described as good boring but 'treacherous' | |
| 60 | | | represents drilling from 65 – 145m which was much the same in papa. | |
| 150 | | | | |
| 160 | | | | |
| 170 | | | Papa occasionally slatty with sand. | |
| 180 | | | | |
| 190 | | | | |
| 200 | | | | |
| 210 | | | | |
| 220 | | | | |
| 230 | | | | |
| 240 | | | | |
| 250 | | | At 251.5m the drilling rods parted, end of bore. | |

## LOG OF BOREHOLE

AREA: MINA | GRID REF: 561 431
BOREHOLE No: 033 · 17 | DATUM (m): a.m.s.l
DRILLER: McLean (1961) | SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS |
|---|---|---|---|---|
| 0 | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | no description recorded. | |
| 4 | clay | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | conglomerate | | | |
| 10 | | | | |
| 11 | | | | |
| 12 | shingle | | no description recorded | no appreciable water. |
| 13 | | | | |
| 14 | | | | |
| 15 | papa. end of bore at 15.2 | | | |

## LOG OF BOREHOLE

AREA: MINA | GRID REF: 568 424
BOREHOLE No: 033 · 19 | DATUM (m): a.m.s.l
DRILLER: McLean (1960) | SCALE:

| Depth in meters below datum | MATERIAL | SYMBOL | DESCRIPTION | AQUIFER CHARACTERISTICS |
|---|---|---|---|---|
| 0 | | | | |
| 1 | clay | | brown clay | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | shingle | | | water bearing |
| 6 | | | | |
| 7 | | | | |
| 8 | gravel & clay | | loose packed conglomerate and brown clay | |
| 9 | | | | |
| 10 | shingle & clay | | blue shingle & blue clay | |
| 11 | | | | |
| 12 | | | | |
| 13 | sand | | blue sand | |
| 14 | | | | |
| 15 | | | | 5.4 – 10.9 m³/day |
| 16 | | | | |
| 35 | Papa | | Mudstone. | |
| 36 | | | | |

# APPENDIX 3·1 – Seismic refraction data and Time / distance curves

Profile: 1

$T_R$: 54

Location: Data from seismic survey. Greta Formation.

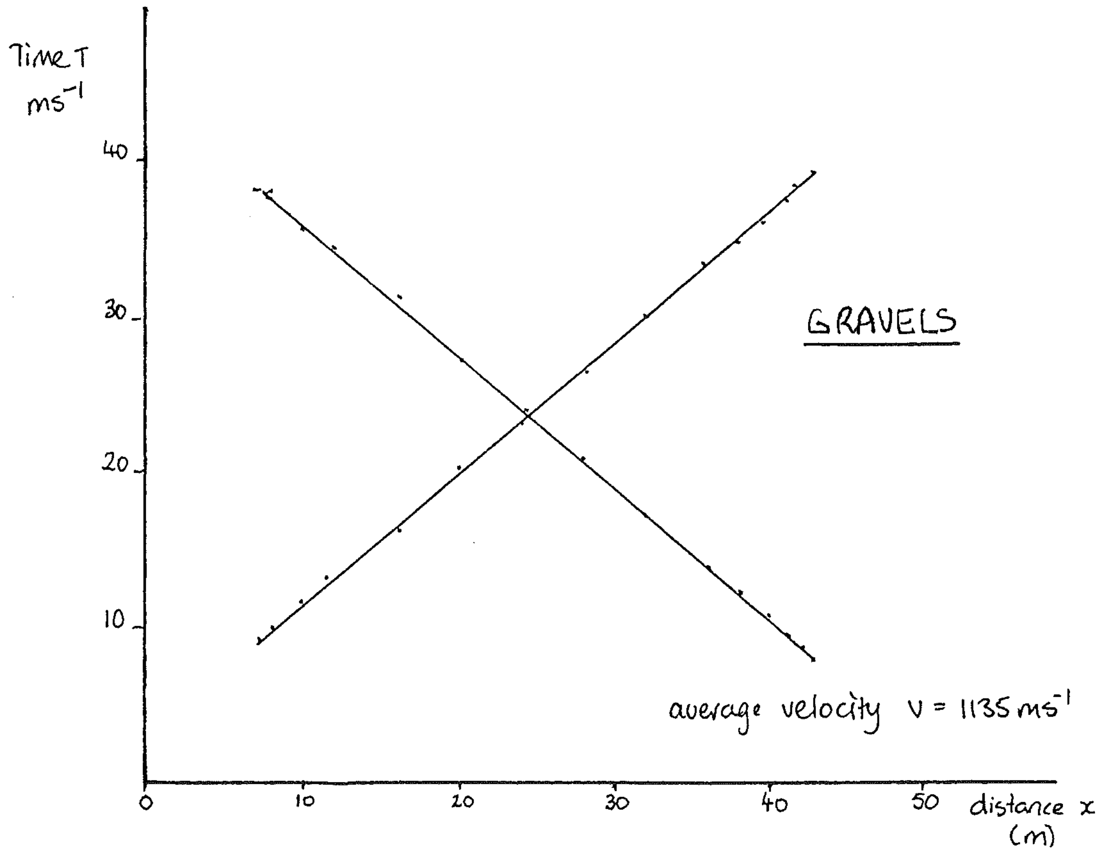
| Station | Ground R.L. | Forward Time | Reverse Time | td $(t_f + t_r - T_R)/2$ | $t_f - t_d$ | $t_r - t_d$ | F | $t_d \cdot F$ |
|---|---|---|---|---|---|---|---|---|
| M | M | MS | MS | MS | MS | MS | $MS^1$ | M |
| 0 | | – | 53·2 | | | | | |
| 1 | | 2·8 | – | | | | | |
| 2 | | 5·2 | – | | | | | |
| 3 | | 7·0 | – | | | | | |
| 4 | | 8·0 | 51·6 | | | | | |
| 5 | | 9·8 | – | | | | | |
| 6 | | 11·4 | – | | | | | |
| 7 | | 13·0 | – | 4·6 | 8·4 | 45·6 | | |
| 8 | | 14·2 | 48·8 | 4·5 | 9·7 | 44·3 | | |
| 10 | | 17·0 | – | 5·0 | 12·0 | 42·0 | | |
| 12 | | 19·0 | 44·0 | 4·5 | 14·5 | 39·5 | | |
| 16 | | 22·8 | 40·4 | 4·6 | 18·2 | 35·8 | | |
| 20 | | 26·6 | 36·0 | 4·3 | 22·3 | 31·7 | | |
| 24 | | 32·4 | 33·2 | 5·8 | 26·6 | 27·4 | | |
| 28 | | 34·4 | 26·8 | 3·6 | 30·8 | 23·2 | | |
| 32 | | 40·4 | 24·0 | 5·2 | 35·2 | 18·8 | | |
| 36 | | 46·0 | 18·8 | 5·4 | 40·6 | 13·4 | | |
| 38 | | – | 16·8 | 4·7 | 41·7 | 12·1 | | |
| 40 | | 48·8 | 14·4 | 4·6 | 44·2 | 9·8 | | |
| 41 | | – | 12·8 | 4·1 | 45·3 | 8·7 | | |
| 42 | | – | 11·6 | 3·9 | 46·2 | 7·7 | | |
| 43 | | – | 10·4 | | | | | |
| 44 | | 50·8 | 8·0 | | | | | |
| 45 | | – | 7·2 | | | | | |
| 46 | | – | 4·8 | | | | | |
| 47 | | – | 1·6 | | | | | |
| 48 | | 54·8 | – | | | | | |

Profile: 1

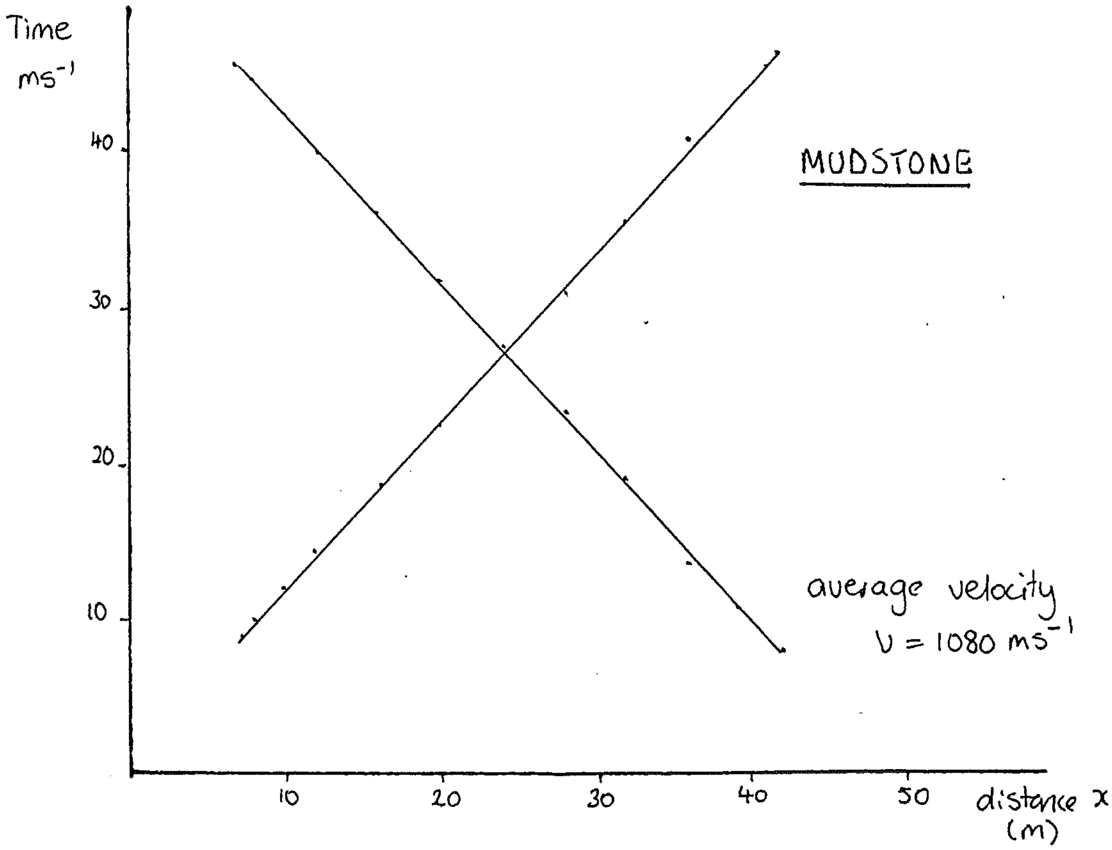
$T_R$: 47

Location: Data from seismic survey. Quaternary gravels.

| Station | Ground R.L. | Forward Time | Reverse Time | td $(t_f + t_r - T_R)/2$ | $t_f - t_d$ | $t_r - t_d$ | F | $t_d \cdot F$ |
|---|---|---|---|---|---|---|---|---|
| M | M | MS | MS | MS | MS | MS | $MS^1$ | M |
| 0 | | – | 46·6 | | | | | |
| 1 | | 6·2 | – | | | | | |
| 2 | | 8·0 | – | | | | | |
| 3 | | 9·0 | – | | | | | |
| 4 | | 10·4 | 43·6 | | | | | |
| 5 | | 12·0 | – | | | | | |
| 6 | | 10·8 | – | | | | | |
| 7 | | 12·0 | 41·2 | 3·1 | 8·9 | 38·1 | | |
| 8 | | 12·6 | 40·0 | 2·8 | 9·8 | 37·2 | | |
| 10 | | 15·2 | 39·0 | 3·6 | 11·6 | 35·4 | | |
| 12 | | 17·0 | 37·8 | 3·6 | 13·4 | 34·2 | | |
| 16 | | 19·8 | 34·8 | 3·8 | 16·0 | 31·0 | | |
| 20 | | 24·8 | 31·6 | 4·7 | 20·1 | 26·9 | | |
| 24 | | 27·8 | 28·6 | 4·7 | 23·1 | 23·9 | | |
| 28 | | 31·0 | 25·4 | 4·7 | 26·3 | 20·7 | | |
| 32 | | 34·6 | 21·8 | 4·7 | 29·9 | 17·1 | | |
| 36 | | 38·4 | 18·6 | 5·0 | 33·4 | 13·6 | | |
| 38 | | 39·2 | 16·8 | 4·5 | 34·7 | 12·3 | | |
| 40 | | 40·4 | 15·0 | 4·2 | 36·2 | 10·8 | | |
| 41 | | 41·6 | 14·0 | 4·3 | 37·3 | 9·7 | | |
| 42 | | 42·4 | 12·8 | 4·1 | 38·3 | 8·7 | | |
| 43 | | 43·2 | 11·8 | 4·0 | 39·2 | 7·8 | | |
| 44 | | 43·6 | 11·4 | | | | | |
| 45 | | – | 9·8 | | | | | |
| 46 | | – | 8·0 | | | | | |
| 47 | | – | 5·0 | | | | | |
| 48 | | 47·4 | | | | | | |



Time T
ms⁻¹
40
30
20
10
0
10
20
30
40
50
distance x
(m)
GRAVELS
average velocity V = 1135 ms⁻¹

Time
ms⁻¹
40
30
20
10
10
20
30
40
50
distance x
(m)
MUDSTONE
average velocity
V = 1080 ms⁻¹

# APPENDIX 3.2 - Electrical resistivity data obtained from soundings carried out in Cheviot region

## A1. INTERPRETED MODEL...

* : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 5.09 RES = 73.45 | | 374.10 | 0.069 |
| | 5.09 | | |
| THICK = 11.76 RES = 151.90 | | 1786.95 | 0.077 |
| | 16.86 | | |
| RES = 15.20 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 73.200 | 73.502 | 0.412 |
| 2 | 1.250 | 73.700 | 73.555 | -0.196 |
| 3 | 1.600 | 73.800 | 73.636 | -0.223 |
| 4 | 2.000 | 73.900 | 73.803 | -0.131 |
| 5 | 2.500 | 74.000 | 74.111 | 0.150 |
| 6 | 3.200 | 74.300 | 74.780 | 0.645 |
| 7 | 4.000 | 75.800 | 75.858 | 0.077 |
| 8 | 5.000 | 77.000 | 77.676 | 0.878 |
| 9 | 6.300 | 84.000 | 80.564 | -4.091 |
| 10 | 8.000 | 84.600 | 84.806 | 0.243 |
| 11 | 10.000 | 89.100 | 89.463 | 0.407 |
| 12 | 12.500 | 91.300 | 94.153 | 3.125 |
| 13 | 16.000 | 95.500 | 97.528 | 2.123 |
| 14 | 20.000 | 95.500 | 97.262 | 1.845 |
| 15 | 25.000 | 94.300 | 92.332 | -2.087 |
| 16 | 32.000 | 84.800 | 81.069 | -4.400 |
| 17 | 40.000 | 68.300 | 66.385 | -2.804 |
| 18 | 50.000 | 48.200 | 50.574 | 4.924 |
| 19 | 63.000 | 35.000 | 36.010 | 2.886 |
| 20 | 80.000 | 29.300 | 25.621 | -12.557 |

RMS P/C ERROR = 1.98

## A2 INTERPRETED MODEL...

* : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 14.41 RES = 145.55 | | 2097.37 | 0.099 |
| | 14.41 | | |
| RES = 30.39 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 148.900 | 145.548 | -2.251 |
| 2 | 1.250 | 144.700 | 145.539 | 0.580 |
| 3 | 1.600 | 148.200 | 145.525 | -1.805 |
| 4 | 2.000 | 141.400 | 145.495 | 2.896 |
| 5 | 2.500 | 142.300 | 145.444 | 2.209 |
| 6 | 3.200 | 140.200 | 145.318 | 3.650 |
| 7 | 4.000 | 142.000 | 145.111 | 2.191 |
| 8 | 5.000 | 145.900 | 144.697 | -0.824 |
| 9 | 6.300 | 147.100 | 143.867 | -2.198 |
| 10 | 8.000 | 147.900 | 142.260 | -3.813 |
| 11 | 10.000 | 145.300 | 139.382 | -4.073 |
| 12 | 12.500 | 135.000 | 134.623 | -0.280 |
| 13 | 16.000 | 124.400 | 125.728 | 1.068 |
| 14 | 20.000 | 112.600 | 113.861 | 1.120 |
| 15 | 25.000 | 93.300 | 98.143 | 5.191 |
| 16 | 32.000 | 76.300 | 78.981 | 3.513 |
| 17 | 40.000 | 64.200 | 62.130 | -3.224 |
| 18 | 50.000 | 51.100 | 49.147 | -3.822 |
| 19 | 63.000 | 41.200 | 40.142 | -2.568 |
| 20 | 80.000 | 34.400 | 35.085 | 1.992 |
| 21 | 100.000 | 32.000 | 32.820 | 2.563 |

RMS P/C ERROR = 2.78

## A3 INTERPRETED MODEL...

* : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 1.29 RES = 99.51 | | 128.42 | 0.013 |
| | 1.29 | | |
| THICK = 13.50 * RES = 157.22 | | 2122.45 | 0.086 |
| | 14.79 | | |
| RES = 30.62 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 98.900 | 101.683 | 2.814 |
| 2 | 1.250 | 102.600 | 103.259 | 0.642 |
| 3 | 1.600 | 104.200 | 106.340 | 2.053 |
| 4 | 2.000 | 107.000 | 110.278 | 3.064 |
| 5 | 2.500 | 107.100 | 115.392 | 7.742 |
| 6 | 3.200 | 110.500 | 121.985 | 10.397 |
| 7 | 4.000 | 115.200 | 128.147 | 11.238 |
| 8 | 5.000 | 123.300 | 133.876 | 8.577 |
| 9 | 6.300 | 136.500 | 138.682 | 1.599 |
| 10 | 8.000 | 137.300 | 141.958 | 3.392 |
| 11 | 10.000 | 142.000 | 142.767 | 0.540 |
| 12 | 12.500 | 138.100 | 140.919 | 2.041 |
| 13 | 16.000 | 120.000 | 134.439 | 12.032 |
| 14 | 20.000 | 105.200 | 123.957 | 17.830 |
| 15 | 25.000 | 82.900 | 108.689 | 31.108 |
| 16 | 32.000 | 70.000 | 88.652 | 26.645 |
| 17 | 40.000 | 54.400 | 69.821 | 28.348 |
| 18 | 50.000 | 44.300 | 54.481 | 22.981 |
| 19 | 63.000 | 36.000 | 43.221 | 20.059 |

RMS P/C ERROR = 14.03

## A4 INTERPRETED MODEL...

* : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 2.62 RES = 1031.91 | | 2702.31 | 0.003 |
| | 2.62 | | |
| THICK = 13.14 RES = 98.87 | | 1298.82 | 0.133 |
| | 15.76 | | |
| RES = 29.52 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 970.300 | 1021.728 | 5.300 |
| 2 | 1.250 | 950.100 | 1011.523 | 6.465 |
| 3 | 1.600 | 985.000 | 993.986 | 0.912 |
| 4 | 2.000 | 1000.000 | 962.675 | -3.732 |
| 5 | 2.500 | 940.000 | 910.596 | -3.128 |
| 6 | 3.200 | 880.000 | 818.666 | -6.970 |
| 7 | 4.000 | 731.700 | 700.970 | -4.200 |
| 8 | 5.000 | 559.000 | 557.373 | -0.291 |
| 9 | 6.300 | 365.200 | 403.681 | 10.537 |
| 10 | 8.000 | 277.500 | 267.774 | -3.505 |
| 11 | 10.000 | 184.200 | 180.042 | -2.258 |
| 12 | 12.500 | 132.500 | 130.772 | -1.304 |
| 13 | 16.000 | 103.000 | 100.543 | -2.385 |
| 14 | 20.000 | 85.600 | 85.660 | 0.070 |
| 15 | 25.000 | 71.600 | 72.915 | 1.836 |
| 16 | 32.000 | 57.000 | 60.042 | 5.338 |
| 17 | 40.000 | 56.000 | 49.462 | -11.675 |
| 18 | 50.000 | 42.000 | 41.535 | -1.108 |
| 19 | 63.000 | 36.000 | 36.160 | 0.444 |
| 20 | 80.000 | 33.000 | 33.045 | 0.138 |
| 21 | 100.000 | 31.000 | 31.596 | 1.922 |

RMS P/C ERROR = 4.24

A5 INTERPRETED MODEL...    * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 5.16 RES = 29.27 | | 151.01 | 0.176 |
| | 5.16 | | |
| THICK = 5.30 RES = 216.86 | | 1149.43 | 0.024 |
| | 10.46 | | |
| RES = 27.27 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 36.900 | 29.311 | -20.566 |
| 2 | 1.250 | 31.600 | 29.358 | -7.095 |
| 3 | 1.600 | 27.500 | 29.429 | 7.015 |
| 4 | 2.000 | 26.800 | 29.578 | 10.365 |
| 5 | 2.500 | 27.900 | 29.852 | 6.995 |
| 6 | 3.200 | 28.100 | 30.447 | 8.351 |
| 7 | 4.000 | 29.900 | 31.416 | 5.070 |
| 8 | 5.000 | 30.300 | 33.061 | 9.111 |
| 9 | 6.300 | 35.800 | 35.736 | -0.180 |
| 10 | 8.000 | 40.200 | 39.781 | -1.042 |
| 11 | 10.000 | 45.000 | 44.602 | -0.885 |
| 12 | 12.500 | 50.600 | 50.020 | -1.146 |
| 13 | 16.000 | 56.100 | 55.733 | -0.653 |
| 14 | 20.000 | 58.700 | 59.560 | 1.499 |
| 15 | 25.000 | 63.200 | 61.253 | -3.080 |
| 16 | 32.000 | 64.300 | 60.026 | -6.648 |
| 17 | 40.000 | 56.400 | 55.997 | -0.715 |
| 18 | 50.000 | 48.000 | 50.193 | 4.569 |
| 19 | 63.000 | 42.000 | 43.471 | 3.502 |
| 20 | 80.000 | 36.100 | 37.432 | 3.690 |
| 21 | 100.000 | 34.100 | 33.154 | -2.773 |

RMS P/C ERROR = 7.32

A6 INTERPRETED MODEL...    * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 3.99 RES = 24.81 | | 99.03 | 0.161 |
| | 3.99 | | |
| THICK = 7.11 RES = 151.94 | | 1080.07 | 0.047 |
| | 11.10 | | |
| RES = 23.01 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 24.900 | 24.883 | -0.067 |
| 2 | 1.250 | 25.000 | 24.962 | -0.152 |
| 3 | 1.600 | 25.300 | 25.093 | -0.816 |
| 4 | 2.000 | 25.700 | 25.351 | -1.358 |
| 5 | 2.500 | 26.200 | 25.823 | -1.438 |
| 6 | 3.200 | 26.200 | 26.784 | 2.230 |
| 7 | 4.000 | 27.900 | 28.298 | 1.425 |
| 8 | 5.000 | 30.300 | 30.645 | 1.139 |
| 9 | 6.300 | 33.900 | 34.182 | 0.832 |
| 10 | 8.000 | 39.900 | 38.974 | -2.320 |
| 11 | 10.000 | 44.400 | 44.205 | -0.439 |
| 12 | 12.500 | 49.900 | 49.499 | -0.803 |
| 13 | 16.000 | 54.900 | 54.547 | -0.642 |
| 14 | 20.000 | 57.900 | 57.414 | -0.840 |
| 15 | 25.000 | 56.600 | 57.882 | 2.266 |
| 16 | 32.000 | 55.900 | 55.290 | -1.091 |
| 17 | 40.000 | 52.500 | 50.220 | -4.343 |
| 18 | 50.000 | 42.000 | 43.818 | 4.329 |
| 19 | 63.000 | 37.200 | 37.015 | -0.498 |
| 20 | 80.000 | 32.000 | 31.373 | -1.961 |
| 21 | 100.000 | 27.500 | 27.629 | 0.469 |

RMS P/C ERROR = 1.08

A7 INTERPRETED MODEL...    * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 0.39 RES = 459.63 | | 180.46 | 0.001 |
| | 0.39 | | |
| THICK = 3.25 RES = 127.70 | | 414.44 | 0.025 |
| | 3.64 | | |
| THICK = 10.34 RES = 68.19 | | 705.35 | 0.152 |
| | 13.98 | | |
| RES = 10.50 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 244.000 | 244.320 | 0.131 |
| 2 | 1.250 | 197.900 | 199.943 | 1.032 |
| 3 | 1.600 | 166.900 | 167.350 | -0.918 |
| 4 | 2.000 | 144.900 | 148.061 | 2.182 |
| 5 | 2.500 | 138.800 | 136.337 | -1.775 |
| 6 | 3.200 | 129.400 | 128.084 | -1.017 |
| 7 | 4.000 | 122.900 | 121.317 | -1.288 |
| 8 | 5.000 | 113.400 | 113.924 | 0.462 |
| 9 | 6.300 | 107.200 | 104.797 | -2.242 |
| 10 | 8.000 | 88.700 | 94.250 | 6.257 |
| 11 | 10.000 | 83.300 | 83.887 | 0.704 |
| 12 | 12.500 | 77.900 | 73.784 | -5.283 |
| 13 | 16.000 | 62.200 | 62.344 | 0.231 |
| 14 | 20.000 | 51.100 | 51.742 | 1.257 |
| 15 | 25.000 | 40.600 | 40.667 | 0.165 |
| 16 | 32.000 | 30.000 | 29.582 | -1.394 |
| 17 | 40.000 | 21.600 | 21.450 | -0.693 |
| 18 | 50.000 | 15.100 | 16.173 | 7.108 |
| 19 | 63.000 | 14.000 | 13.153 | -6.053 |
| 20 | 80.000 | 13.300 | 11.691 | -12.095 |
| 21 | 100.000 | 10.400 | 11.173 | 7.434 |

RMS P/C ERROR 3.85

A8 INTERPRETED MODEL...    * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 0.48 RES = 170.00 | | 82.41 | 0.003 |
| | 0.48 | | |
| THICK = 6.81 RES = 55.17 | | 375.45 | 0.123 |
| | 7.29 | | |
| THICK = 8.40 RES = 176.60 | | 1483.48 | 0.048 |
| | 15.69 | | |
| RES = 20.79 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 115.800 | 113.115 | -2.318 |
| 2 | 1.250 | 92.400 | 95.995 | 3.890 |
| 3 | 1.600 | 77.400 | 80.533 | 4.048 |
| 4 | 2.000 | 72.500 | 70.206 | -3.164 |
| 5 | 2.500 | 64.600 | 63.812 | -1.219 |
| 6 | 3.200 | 61.700 | 60.112 | -2.573 |
| 7 | 4.000 | 62.600 | 58.750 | -6.149 |
| 8 | 5.000 | 59.200 | 58.705 | -0.836 |
| 9 | 6.300 | 55.100 | 59.723 | 8.391 |
| 10 | 8.000 | 61.400 | 62.113 | 1.162 |
| 11 | 10.000 | 63.700 | 65.442 | 2.734 |
| 12 | 12.500 | 67.500 | 69.815 | 3.429 |
| 13 | 16.000 | 73.100 | 74.577 | 2.021 |
| 14 | 20.000 | 78.700 | 77.525 | -1.492 |
| 15 | 25.000 | 81.600 | 77.539 | -4.977 |
| 16 | 32.000 | 79.300 | 73.149 | -7.757 |
| 17 | 40.000 | 67.300 | 64.962 | -3.474 |
| 18 | 50.000 | 53.600 | 54.456 | 1.597 |
| 19 | 63.000 | 40.900 | 43.191 | 5.601 |
| 20 | 80.000 | 32.000 | 33.745 | 5.453 |
| 21 | 100.000 | 28.500 | 27.565 | -3.280 |

RMS P/C ERROR = 4.21

A9 . INTERPRETED MODEL...          * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 4.79 RES = 32.76 | | 156.97 | 0.146 |
| | 4.79 | | |
| THICK = 7.69 RES = 87.43 | | 671.97 | 0.088 |
| | 12.48 | | |
| RES = 12.38 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 33.000 | 32.789 | -0.639 |
| 2 | 1.250 | 32.900 | 32.825 | -0.228 |
| 3 | 1.600 | 33.400 | 32.881 | -1.555 |
| 4 | 2.000 | 33.000 | 32.995 | -0.016 |
| 5 | 2.500 | 32.900 | 33.205 | 0.928 |
| 6 | 3.200 | 33.300 | 33.653 | 1.061 |
| 7 | 4.000 | 34.100 | 34.370 | 0.793 |
| 8 | 5.000 | 35.000 | 35.543 | 1.552 |
| 9 | 6.300 | 38.200 | 37.356 | -2.210 |
| 10 | 8.000 | 39.100 | 39.891 | 2.023 |
| 11 | 10.000 | 42.500 | 42.534 | 0.080 |
| 12 | 12.500 | 45.200 | 44.926 | -0.606 |
| 13 | 16.000 | 46.600 | 46.268 | -0.712 |
| 14 | 20.000 | 45.800 | 45.498 | -0.658 |
| 15 | 25.000 | 40.500 | 42.354 | 4.577 |
| 16 | 32.000 | 37.000 | 36.597 | -1.089 |
| 17 | 40.000 | 29.700 | 30.066 | 1.234 |
| 18 | 50.000 | 24.100 | 23.969 | -0.543 |
| 19 | 63.000 | 18.800 | 18.921 | 0.642 |
| 20 | 80.000 | 16.400 | 15.510 | -5.426 |

RMS P/C ERROR = 0.89

A10 INTERPRETED MODEL...          * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 8.32 RES = 20.28 | | 168.65 | 0.410 |
| | 8.32 | | |
| THICK = 5.34 RES = 163.05 | | 870.26 | 0.033 |
| | 13.65 | | |
| RES = 7.42 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 20.000 | 20.283 | 1.416 |
| 2 | 1.250 | 20.200 | 20.291 | 0.451 |
| 3 | 1.600 | 20.200 | 20.302 | 0.504 |
| 4 | 2.000 | 20.400 | 20.325 | -0.366 |
| 5 | 2.500 | 20.400 | 20.368 | -0.158 |
| 6 | 3.200 | 20.700 | 20.468 | -1.122 |
| 7 | 4.000 | 21.000 | 20.634 | -1.745 |
| 8 | 5.000 | 21.400 | 20.950 | -2.102 |
| 9 | 6.300 | 21.800 | 21.527 | -1.253 |
| 10 | 8.000 | 22.000 | 22.571 | 2.594 |
| 11 | 10.000 | 23.200 | 24.036 | 3.605 |
| 12 | 12.500 | 25.900 | 26.140 | 0.928 |
| 13 | 16.000 | 29.400 | 28.882 | -1.763 |
| 14 | 20.000 | 32.200 | 31.353 | -2.631 |
| 15 | 25.000 | 33.500 | 33.097 | -1.203 |
| 16 | 32.000 | 32.800 | 33.435 | 1.937 |
| 17 | 40.000 | 31.200 | 31.763 | 1.805 |
| 18 | 50.000 | 29.000 | 28.341 | -2.273 |

RMS P/C ERROR = 1.67

A11 INTERPRETED MODEL...          * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 0.96 RES = 9.63 | | 9.29 | 0.100 |
| | 0.96 | | |
| THICK = 7.74 RES = 112.59 | | 871.92 | 0.069 |
| | 8.71 | | |
| RES = 8.72 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 11.500 | 11.514 | 0.125 |
| 2 | 1.250 | 12.900 | 12.796 | -0.808 |
| 3 | 1.600 | 14.900 | 14.962 | 0.419 |
| 4 | 2.000 | 17.900 | 17.648 | -1.410 |
| 5 | 2.500 | 21.200 | 21.024 | -0.832 |
| 6 | 3.200 | 25.700 | 25.544 | -0.606 |
| 7 | 4.000 | 29.600 | 30.214 | 2.073 |
| 8 | 5.000 | 34.700 | 35.350 | 1.872 |
| 9 | 6.300 | 40.300 | 40.927 | 1.557 |
| 10 | 8.000 | 45.000 | 46.574 | 3.498 |
| 11 | 10.000 | 51.200 | 51.107 | -0.181 |
| 12 | 12.500 | 56.000 | 54.204 | -3.207 |
| 13 | 16.000 | 57.500 | 54.837 | -4.631 |
| 14 | 20.000 | 54.200 | 52.191 | -3.707 |
| 15 | 25.000 | 47.200 | 46.260 | -1.992 |
| 16 | 32.000 | 33.800 | 37.093 | 9.743 |
| 17 | 40.000 | 27.700 | 27.833 | 0.478 |
| 18 | 50.000 | 20.800 | 20.073 | -3.496 |
| 19 | 63.000 | 14.900 | 14.338 | -3.771 |
| 20 | 80.000 | 11.200 | 11.178 | -0.194 |
| 21 | 100.000 | 9.500 | 9.750 | 2.631 |
| 22 | 125.000 | 9.100 | 9.132 | 0.348 |

RMS P/C ERROR = 3.50

B1 INTERPRETED MODEL...          * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 2.88 RES = 42.93 | | 123.62 | 0.067 |
| | 2.88 | | |
| THICK = 6.62 RES = 95.97 | | 635.57 | 0.069 |
| | 9.50 | | |
| RES = 22.22 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 52.800 | 43.092 | -18.386 |
| 2 | 1.250 | 44.800 | 43.250 | -3.460 |
| 3 | 1.600 | 39.400 | 43.549 | 10.530 |
| 4 | 2.000 | 37.500 | 44.075 | 17.534 |
| 5 | 2.500 | 40.900 | 44.999 | 10.022 |
| 6 | 3.200 | 44.200 | 46.660 | 5.566 |
| 7 | 4.000 | 49.600 | 48.991 | -1.228 |
| 8 | 5.000 | 53.100 | 52.007 | -2.056 |
| 9 | 6.300 | 60.300 | 55.666 | -7.684 |
| 10 | 8.000 | 60.900 | 59.265 | -2.685 |
| 11 | 10.000 | 62.800 | 61.631 | -1.862 |
| 12 | 12.500 | 61.100 | 62.071 | 1.589 |
| 13 | 16.000 | 57.100 | 59.636 | 4.441 |
| 14 | 20.000 | 50.600 | 54.726 | 8.155 |
| 15 | 25.000 | 48.100 | 47.847 | -0.527 |
| 16 | 32.000 | 42.700 | 39.764 | -6.876 |
| 17 | 40.000 | 35.100 | 33.334 | -5.030 |
| 18 | 50.000 | 27.200 | 28.633 | 5.267 |
| 19 | 63.000 | 26.000 | 25.646 | -1.362 |
| 20 | 80.000 | 23.500 | 23.969 | 1.996 |
| 21 | 100.000 | 23.000 | 23.226 | 0.983 |

RMS P/C ERROR = 7.88

## B2 INTERPRETED MODEL...

* : FIXED PARAMETER

| Layer | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 1.58 RES = 69.89 | | 110.25 | 0.023 |
| | 1.58 | | |
| THICK = 11.33 RES = 122.59 | | 1388.95 | 0.092 |
| | 12.91 | | |
| RES = 30.13 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 76.000 | 70.977 | -6.609 |
| 2 | 1.250 | 73.200 | 71.825 | -1.878 |
| 3 | 1.600 | 68.100 | 73.589 | 8.060 |
| 4 | 2.000 | 71.400 | 76.042 | 6.502 |
| 5 | 2.500 | 75.600 | 79.568 | 5.248 |
| 6 | 3.200 | 86.100 | 84.564 | -1.784 |
| 7 | 4.000 | 97.000 | 89.790 | -7.433 |
| 8 | 5.000 | 96.600 | 95.087 | -1.567 |
| 9 | 6.300 | 98.200 | 99.981 | 1.814 |
| 10 | 8.000 | 106.200 | 103.745 | -2.312 |
| 11 | 10.000 | 109.500 | 105.345 | -3.795 |
| 12 | 12.500 | 103.000 | 104.520 | 1.475 |
| 13 | 16.000 | 93.900 | 99.821 | 6.306 |
| 14 | 20.000 | 92.300 | 91.892 | -0.442 |
| 15 | 25.000 | 79.200 | 80.608 | 1.777 |
| 16 | 32.000 | 67.500 | 66.543 | -1.417 |
| 17 | 40.000 | 54.400 | 54.188 | -0.390 |
| 18 | 50.000 | 44.300 | 44.576 | 0.623 |
| 19 | 63.000 | 37.800 | 37.886 | 0.229 |
| 20 | 80.000 | 34.500 | 34.020 | -1.391 |
| 21 | 100.000 | 32.000 | 32.234 | 0.730 |

RMS P/C ERROR = 3.66

## B3 INTERPRETED MODEL...

* : FIXED PARAMETER

| Layer | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 17.14 RES = 134.78 | | 2310.04 | 0.127 |
| | 17.14 | | |
| RES = 32.81 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 143.000 | 134.778 | -5.750 |
| 2 | 1.250 | 140.600 | 134.773 | -4.144 |
| 3 | 1.600 | 139.300 | 134.766 | -3.255 |
| 4 | 2.000 | 137.500 | 134.750 | -2.000 |
| 5 | 2.500 | 136.900 | 134.723 | -1.590 |
| 6 | 3.200 | 136.900 | 134.657 | -1.638 |
| 7 | 4.000 | 139.000 | 134.550 | -3.201 |
| 8 | 5.000 | 129.700 | 134.335 | 3.574 |
| 9 | 6.300 | 130.900 | 133.897 | 2.290 |
| 10 | 8.000 | 125.500 | 133.041 | 6.009 |
| 11 | 10.000 | 120.600 | 131.445 | 8.993 |
| 12 | 12.500 | 115.800 | 128.751 | 11.184 |
| 13 | 16.000 | 119.300 | 123.381 | 3.421 |
| 14 | 20.000 | 120.400 | 115.651 | -3.945 |
| 15 | 25.000 | 105.800 | 104.422 | -1.303 |
| 16 | 32.000 | 95.700 | 88.936 | -7.068 |
| 17 | 40.000 | 71.300 | 73.258 | 2.747 |
| 18 | 50.000 | 57.500 | 59.299 | 3.129 |
| 19 | 63.000 | 45.800 | 47.992 | 4.787 |
| 20 | 80.000 | 40.500 | 40.725 | 0.555 |
| 21 | 100.000 | 37.900 | 36.869 | -2.720 |

RMS P/C ERROR = 4.62

## B4 INTERPRETED MODEL...

* : FIXED PARAMETER

| Layer | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 2.23 RES = 138.58 | | 309.50 | 0.016 |
| | 2.23 | | |
| THICK = 1.32 RES = 841.99 | | 1107.93 | 0.002 |
| | 3.55 | | |
| THICK = 11.90 * RES = 130.70 | | 1555.34 | 0.091 |
| | 15.45 | | |
| RES = 40.52 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 145.900 | 140.402 | -3.768 |
| 2 | 1.250 | 146.100 | 141.952 | -2.839 |
| 3 | 1.600 | 146.300 | 145.269 | -0.705 |
| 4 | 2.000 | 146.100 | 150.379 | 2.929 |
| 5 | 2.500 | 156.700 | 158.611 | 1.220 |
| 6 | 3.200 | 168.800 | 171.466 | 1.579 |
| 7 | 4.000 | 195.000 | 186.559 | -4.329 |
| 8 | 5.000 | 220.200 | 202.254 | -8.150 |
| 9 | 6.300 | 230.200 | 215.977 | -6.179 |
| 10 | 8.000 | 223.000 | 223.011 | 0.005 |
| 11 | 10.000 | 217.900 | 220.629 | 1.252 |
| 12 | 12.500 | 212.700 | 208.460 | -1.994 |
| 13 | 16.000 | 160.300 | 185.824 | 15.923 |
| 14 | 20.000 | 145.500 | 159.968 | 9.944 |
| 15 | 25.000 | 133.400 | 132.316 | -0.812 |
| 16 | 32.000 | 111.100 | 103.669 | -6.689 |
| 17 | 40.000 | 90.800 | 81.505 | -10.237 |
| 18 | 50.000 | 73.900 | 65.058 | -11.964 |
| 19 | 63.000 | 58.600 | 53.725 | -8.318 |
| 20 | 80.000 | 46.700 | 47.169 | 1.005 |
| 21 | 100.000 | 41.600 | 44.067 | 5.929 |
| 22 | 125.000 | 38.300 | 42.516 | 11.008 |

RMS P/C ERROR = 6.12

## B5 INTERPRETED MODEL...

* : FIXED PARAMETER

| Layer | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 0.64 RES = 147.32 | | 94.57 | 0.004 |
| | 0.64 | | |
| THICK = 6.87 RES = 46.05 | | 316.18 | 0.149 |
| | 7.51 | | |
| THICK = 6.50 RES = 132.13 | | 858.67 | 0.049 |
| | 14.01 | | |
| RES = 12.20 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 116.800 | 114.862 | -1.659 |
| 2 | 1.250 | 101.400 | 100.913 | -0.480 |
| 3 | 1.600 | 80.500 | 84.169 | 4.558 |
| 4 | 2.000 | 70.800 | 70.917 | 0.165 |
| 5 | 2.500 | 63.000 | 61.154 | -2.929 |
| 6 | 3.200 | 54.900 | 54.165 | -1.339 |
| 7 | 4.000 | 48.300 | 51.058 | 5.709 |
| 8 | 5.000 | 51.100 | 49.762 | -2.619 |
| 9 | 6.300 | 51.900 | 49.747 | -4.148 |
| 10 | 8.000 | 50.400 | 50.842 | 0.877 |
| 11 | 10.000 | 49.100 | 52.550 | 7.026 |
| 12 | 12.500 | 53.000 | 54.714 | 3.233 |
| 13 | 16.000 | 55.200 | 56.466 | 2.294 |
| 14 | 20.000 | 58.400 | 56.422 | -3.386 |
| 15 | 25.000 | 58.400 | 53.704 | -8.042 |
| 16 | 32.000 | 50.200 | 47.446 | -5.486 |
| 17 | 40.000 | 36.600 | 39.320 | 7.431 |
| 18 | 50.000 | 29.100 | 30.838 | 5.972 |
| 19 | 63.000 | 23.000 | 23.162 | 0.706 |
| 20 | 80.000 | 19.900 | 17.702 | -11.044 |

RMS P/C ERROR = 4.19

B6 INTERPRETED MODEL...  * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 0.82 RES = 175.31 | | 143.31 | 0.005 |
| | 0.82 | | |
| THICK = 7.66 RES = 51.29 | | 392.98 | 0.149 |
| | 8.48 | | |
| THICK = 8.65 RES = 194.94 | | 1685.92 | 0.044 |
| | 17.13 | | |
| RES = 16.03 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 155.000 | 150.338 | -3.008 |
| 2 | 1.250 | 130.300 | 136.999 | 5.141 |
| 3 | 1.600 | 115.200 | 117.044 | 1.601 |
| 4 | 2.000 | 94.500 | 98.664 | 4.406 |
| 5 | 2.500 | 83.700 | 82.416 | -1.534 |
| 6 | 3.200 | 71.500 | 68.863 | -3.658 |
| 7 | 4.000 | 63.500 | 61.703 | -2.829 |
| 8 | 5.000 | 60.000 | 57.892 | -3.513 |
| 9 | 6.300 | 57.700 | 56.819 | -1.526 |
| 10 | 8.000 | 54.900 | 57.778 | 5.243 |
| 11 | 10.000 | 55.500 | 60.204 | 8.476 |
| 12 | 12.500 | 64.500 | 64.028 | -0.732 |
| 13 | 16.000 | 68.900 | 68.941 | 0.059 |
| 14 | 20.000 | 73.700 | 72.924 | -1.053 |
| 15 | 25.000 | 76.300 | 74.778 | -1.995 |
| 16 | 32.000 | 75.300 | 72.835 | -3.273 |
| 17 | 40.000 | 69.300 | 66.595 | -3.904 |
| 18 | 50.000 | 59.100 | 56.894 | -3.733 |
| 19 | 63.000 | 43.500 | 45.079 | 3.629 |
| 20 | 80.000 | 31.400 | 33.710 | 7.358 |
| 21 | 100.000 | 26.300 | 25.693 | -2.308 |

RMS P/C ERROR = 3.88

B7 INTERPRETED MODEL...  * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 5.23 RES = 57.06 | | 298.70 | 0.092 |
| | 5.23 | | |
| THICK = 6.11 RES = 170.47 | | 1041.59 | 0.036 |
| | 11.34 | | |
| RES = 32.12 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 61.700 | 57.106 | -7.445 |
| 2 | 1.250 | 59.900 | 57.158 | -4.578 |
| 3 | 1.600 | 56.400 | 57.236 | 1.482 |
| 4 | 2.000 | 56.200 | 57.400 | 2.134 |
| 5 | 2.500 | 55.800 | 57.701 | 3.407 |
| 6 | 3.200 | 56.800 | 58.356 | 2.739 |
| 7 | 4.000 | 56.400 | 59.414 | 5.344 |
| 8 | 5.000 | 59.300 | 61.195 | 3.195 |
| 9 | 6.300 | 63.100 | 64.022 | 1.461 |
| 10 | 8.000 | 67.300 | 68.147 | 1.259 |
| 11 | 10.000 | 72.900 | 72.637 | -0.360 |
| 12 | 12.500 | 79.900 | 76.993 | -3.638 |
| 13 | 16.000 | 83.300 | 79.986 | -3.979 |
| 14 | 20.000 | 81.700 | 79.721 | -2.423 |
| 15 | 25.000 | 70.700 | 75.840 | 7.270 |
| 16 | 32.000 | 67.500 | 68.092 | 0.876 |
| 17 | 40.000 | 57.400 | 59.043 | 2.862 |
| 18 | 50.000 | 51.000 | 50.400 | -1.177 |
| 19 | 63.000 | 44.000 | 43.063 | -2.131 |
| 20 | 80.000 | 38.000 | 38.090 | 0.236 |
| 21 | 100.000 | 35.000 | 35.330 | 0.941 |

RMS P/C ERROR = 2.93

D1 INTERPRETED MODEL...  * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 0.02 RES = 4.86 | | 0.11 | 0.005 |
| | 0.02 | | |
| THICK = 7.65 RES = 153.75 | | 1176.37 | 0.050 |
| | 7.67 | | |
| THICK = 25.52 RES = 967.92 | | 24700.04 | 0.026 |
| | 33.19 | | |
| RES = 73.20 | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 92.200 | 96.589 | 4.761 |
| 2 | 1.250 | 104.300 | 106.418 | 2.031 |
| 3 | 1.600 | 121.200 | 116.551 | -3.836 |
| 4 | 2.000 | 132.400 | 124.876 | -5.683 |
| 5 | 2.500 | 135.600 | 132.249 | -2.471 |
| 6 | 3.200 | 145.100 | 139.462 | -3.886 |
| 7 | 4.000 | 145.400 | 145.381 | -0.013 |
| 8 | 5.000 | 147.000 | 151.545 | 3.092 |
| 9 | 6.300 | 151.900 | 159.207 | 4.811 |
| 0 | 8.000 | 163.400 | 170.465 | 4.324 |
| 1 | 10.000 | 181.800 | 185.557 | 2.066 |
| 2 | 12.500 | 213.500 | 207.567 | -2.779 |
| 3 | 16.000 | 240.300 | 239.862 | -0.182 |
| 4 | 20.000 | 280.700 | 276.057 | -1.654 |
| 5 | 25.000 | 321.700 | 316.065 | -1.752 |
| 6 | 32.000 | 372.600 | 360.257 | -3.313 |
| 7 | 40.000 | 386.300 | 394.321 | 2.076 |
| 8 | 50.000 | 396.600 | 416.099 | 4.917 |
| 9 | 63.000 | 399.800 | 418.707 | 4.729 |
| 0 | 80.000 | 417.000 | 394.066 | -5.500 |
| 1 | 100.000 | 355.000 | 347.119 | -2.220 |
| 2 | 125.000 | 270.100 | 281.800 | 4.332 |
| 3 | 160.000 | 210.700 | 208.770 | -0.916 |
| 4 | 200.000 | 140.400 | 151.904 | 8.193 |

RMS P/C ERROR = 3.13

D2 NTERPRETED MODEL...  * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 1.67 RES = 65.92 | | 109.82 | 0.025 |
| | 1.67 | | |
| THICK = 47.76 RES = 452.55 | | 21612.72 | 0.106 |
| | 49.42 | | |
| RES = 20.60 * | | | |

| L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|
| 1.000 | 63.400 | 68.567 | 8.151 |
| 1.250 | 69.500 | 70.686 | 1.707 |
| 1.600 | 77.700 | 75.201 | -3.217 |
| 2.000 | 90.600 | 81.744 | -9.775 |
| 2.500 | 101.500 | 91.631 | [illegible].724 |
| 3.200 | 116.400 | 106.949 | -8.119 |
| 4.000 | 131.800 | 124.885 | -5.246 |
| 5.000 | 147.200 | 146.317 | -0.600 |
| 6.300 | 163.600 | 171.457 | 4.802 |
| 8.000 | 190.100 | 199.972 | 5.193 |
| 10.000 | 211.200 | 228.189 | 8.044 |
| 12.500 | 240.200 | 257.070 | 7.023 |
| 16.000 | 265.900 | 288.515 | 8.505 |
| 20.000 | 289.700 | 314.979 | 8.726 |
| 25.000 | 317.300 | 337.970 | 6.514 |
| 32.000 | 349.900 | 356.559 | 1.903 |
| 40.000 | 377.100 | 364.794 | -3.263 |
| 50.000 | 380.300 | 360.883 | -5.106 |
| 63.000 | 363.500 | 340.679 | -6.278 |
| 80.000 | 337.800 | 299.523 | -11.331 |
| 100.000 | 270.000 | 244.529 | -9.434 |
| 125.000 | 190.700 | 179.605 | -5.818 |
| 160.000 | 97.400 | 114.048 | 17.093 |
| 200.000 | 59.500 | 68.479 | 15.090 |

S P/C ERROR = 7.25

D3 INTERPRETED MODEL...  * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 1.86 RES = 13.37 | | 24.93 | 0.140 |
| | 1.86 | | |
| THICK = 29.43 RES = 361.63 | | 10644.00 | 0.081 |
| | 31.30 | | |
| RES = 36.00 * | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 14.600 | 13.874 | -4.972 |
| 2 | 1.250 | 13.900 | 14.297 | 2.860 |
| 3 | 1.600 | 14.700 | 15.216 | 3.509 |
| 4 | 2.000 | 15.600 | 16.608 | 6.459 |
| 5 | 2.500 | 18.600 | 18.823 | 1.201 |
| 6 | 3.200 | 22.500 | 22.467 | -0.149 |
| 7 | 4.000 | 27.400 | 27.063 | -1.228 |
| 8 | 5.000 | 34.200 | 32.980 | -3.569 |
| 9 | 6.300 | 40.600 | 40.550 | -0.124 |
| 10 | 8.000 | 49.400 | 50.044 | 1.303 |
| 11 | 10.000 | 59.400 | 60.560 | 1.952 |
| 12 | 12.500 | 73.400 | 72.775 | -0.851 |
| 13 | 16.000 | 89.600 | 88.251 | -1.505 |
| 14 | 20.000 | 110.600 | 103.797 | -6.151 |
| 15 | 25.000 | 119.100 | 120.313 | 1.018 |
| 16 | 32.000 | 139.700 | 138.446 | -0.898 |
| 17 | 40.000 | 151.000 | 153.090 | 1.384 |
| 18 | 50.000 | 160.200 | 163.641 | 2.146 |
| 19 | 63.000 | 162.300 | 167.659 | 3.302 |
| 20 | 80.000 | 158.000 | 161.782 | 2.394 |
| 21 | 100.000 | 147.100 | 146.845 | -0.173 |
| 22 | 125.000 | 124.800 | 123.852 | -0.759 |
| 23 | 160.000 | 98.000 | 96.134 | -1.904 |
| 24 | 200.000 | 75.200 | 73.001 | -2.925 |

RMS P/C ERROR = 2.81

D4 INTERPRETED MODEL...  * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 6.14 RES = 34.46 | | 211.41 | 0.178 |
| | 6.14 | | |
| THICK = 30.54 RES = 280.73 | | 8572.52 | 0.109 |
| | 36.67 | | |
| RES = 35.00 * | | | |

SPOTS10

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 37.200 | 34.490 | -7.285 |
| 2 | 1.250 | 36.900 | 34.528 | -6.427 |
| 3 | 1.600 | 35.200 | 34.585 | -1.748 |
| 4 | 2.000 | 33.300 | 34.706 | 4.223 |
| 5 | 2.500 | 32.800 | 34.930 | 6.495 |
| 6 | 3.200 | 33.700 | 35.438 | 5.156 |
| 7 | 4.000 | 34.700 | 36.276 | 4.541 |
| 8 | 5.000 | 36.100 | 37.795 | 4.695 |
| 9 | 6.300 | 40.700 | 40.442 | -0.635 |
| 10 | 8.000 | 47.100 | 44.918 | -4.632 |
| 11 | 10.000 | 53.400 | 51.003 | -4.489 |
| 12 | 12.500 | 61.700 | 59.275 | -3.930 |
| 13 | 16.000 | 68.800 | 70.711 | 2.778 |
| 14 | 20.000 | 80.600 | 82.719 | 2.629 |
| 15 | 25.000 | 90.200 | 95.720 | 6.120 |
| 16 | 32.000 | 108.000 | 110.213 | 2.049 |
| 17 | 40.000 | 122.300 | 122.165 | -0.111 |
| 18 | 50.000 | 135.300 | 131.223 | -3.013 |
| 19 | 63.000 | 139.200 | 135.550 | -2.622 |
| 20 | 80.000 | 137.000 | 132.476 | -3.302 |
| 21 | 100.000 | 120.200 | 122.298 | 1.746 |
| 22 | 125.000 | 105.400 | 105.595 | 0.185 |
| 23 | 160.000 | 84.200 | 84.678 | 0.567 |
| 24 | 200.000 | 65.400 | 66.600 | 1.835 |

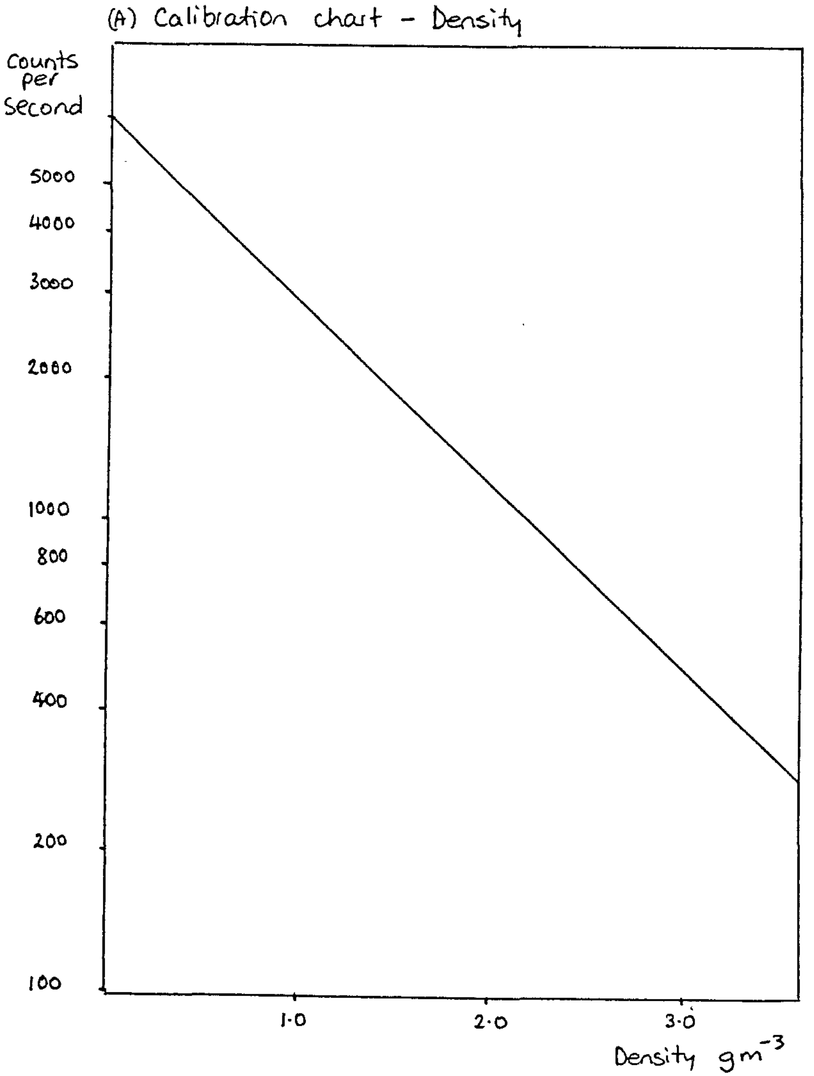
RMS P/C ERROR = 3.69

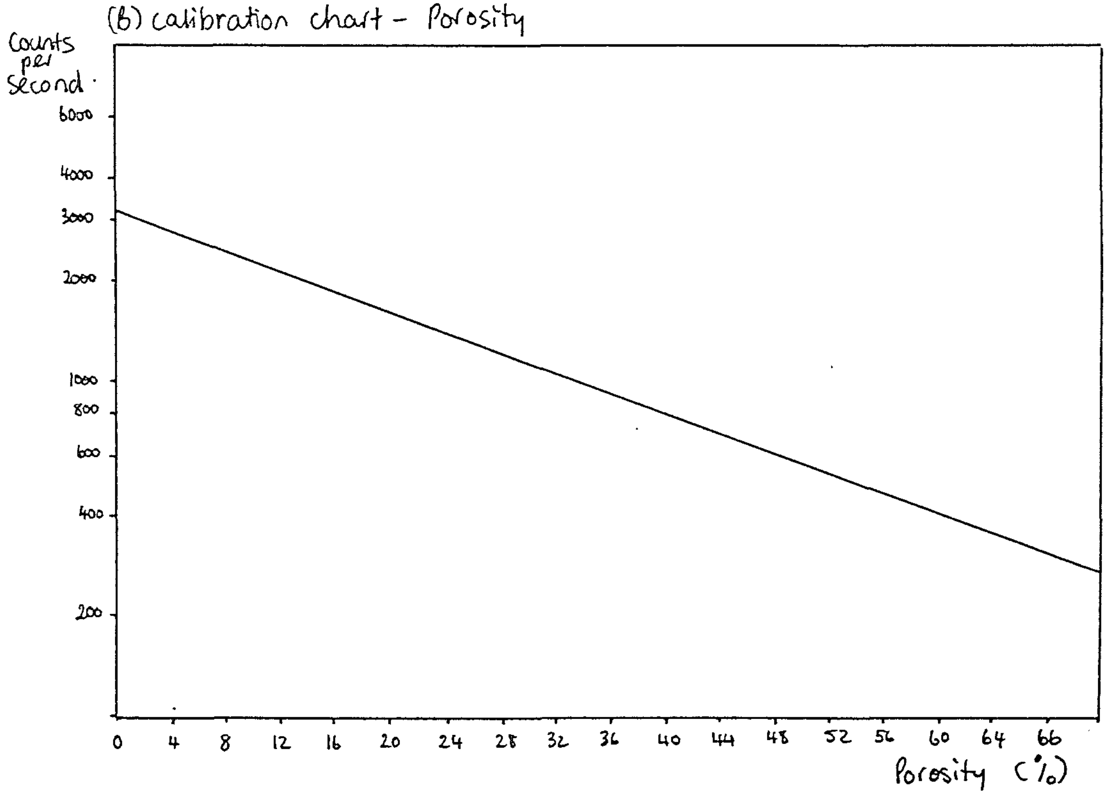
D5 INTERPRETED MODEL...  * : FIXED PARAMETER

| | DEPTH | T=THICK*RES | S=THICK/RES |
|---|---|---|---|
| | 0.00 | | |
| THICK = 0.55 RES = 59.37 | | 32.90 | 0.009 |
| | 0.55 | | |
| THICK = 10.27 RES = 19.24 | | 197.62 | 0.534 |
| | 10.83 | | |
| THICK = 78.49 RES = 167.27 | | 13129.07 | 0.469 |
| | 89.32 | | |
| RES = 26.30 * | | | |

| I | L | RA-FIELD | RA-MODEL | P/C ERROR |
|---|---|---|---|---|
| 1 | 1.000 | 42.600 | 42.994 | 0.925 |
| 2 | 1.250 | 37.800 | 37.051 | -1.983 |
| 3 | 1.600 | 31.300 | 30.907 | -1.254 |
| 4 | 2.000 | 26.500 | 26.447 | -0.201 |
| 5 | 2.500 | 23.000 | 23.451 | 1.962 |
| 6 | 3.200 | 21.100 | 21.499 | 1.890 |
| 7 | 4.000 | 20.300 | 20.669 | 1.819 |
| 8 | 5.000 | 20.100 | 20.382 | 1.402 |
| 9 | 6.300 | 20.400 | 20.496 | 0.471 |
| 10 | 8.000 | 21.900 | 21.105 | -3.628 |
| 11 | 10.000 | 22.900 | 22.261 | -2.789 |
| 12 | 12.500 | 24.900 | 24.268 | -2.538 |
| 13 | 16.000 | 27.900 | 27.686 | -0.767 |
| 14 | 20.000 | 31.800 | 32.104 | 0.957 |
| 15 | 25.000 | 37.200 | 37.750 | 1.478 |
| 16 | 32.000 | 44.400 | 45.360 | 2.162 |
| 17 | 40.000 | 52.700 | 53.162 | 0.877 |
| 18 | 50.000 | 61.700 | 61.643 | -0.092 |
| 19 | 63.000 | 71.200 | 70.685 | -0.723 |
| 20 | 80.000 | 80.700 | 79.640 | -1.314 |
| 21 | 100.000 | 87.300 | 86.644 | -0.752 |
| 22 | 125.000 | 93.300 | 91.217 | -2.233 |
| 23 | 160.000 | 89.100 | 91.929 | 3.175 |
| 24 | 200.000 | 77.100 | 87.746 | 13.808 |

RMS P/C ERROR = 1.45




APPENDIX 3.3- Calibration charts for density and porosity logs :

APPENDIX 4·1 - Mean temperatures and rainfalls observed by Cheviot area School at Cheviot climate Station.

| Month | Air Temperature and Humidity at Observation Hour | | | | Temperatures | | | | | | | | | | | | Cld Amt | Rainfall | | | | | Weather Phenomena | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Means | | | Extreme Max. and Min. | | | | Range | | Grass Min. | | | | | | No. of Days | | Number of Days | | | | | | |
| | Dry Bulb | Wet Bulb | RH | VP | Daily Max. | Daily Min. | Daily Mean | Max. | Date | Min. | Date | Daily Mean | Extreme | Daily Mean | Lowest | | Total | Max. Daily Fall | Date | ≥0.1 mm | ≥1.0 mm | g | s | h | t | f | Xg | Xs |
| | °c | °c | % | mb | °c | °c | °c | °c | | °c | | °c | °c | °c | °c | | mm | mm | | | | | | | | | | |
| JAN | 18.7 | 16.0 | 74 | 16.0 | 23.8 | 13.0 | 18.4 | 30.5 | 17 | 3.9 | 30 | 10.8 | 26.6 | 11.5 | 2.5 | 5.1 | 37 | 16 | 28 | 8 | 4 | • | • | • | • | • | • | • |
| FEB | 15.2 | 13.9 | 86 | 14.8 | 21.6 | 10.8 | 16.2 | 31.8 | 11 | 4.6 | 9 | 10.8 | 27.2 | 9.1 | 2.6 | 5.1 | 143 | [illegible] | 24 | 10 | 8 | • | • | • | • | 1 | • | • |
| MAR | 14.3 | 12.7 | 82 | 13.4 | 19.7 | 8.9 | 14.3 | 27.8 | 8 | 1.1 | 23 | 10.8 | 26.7 | 7.6 | 0.1 | 5.1 | 111 | 43 | 30 | 12 | 11 | • | • | • | • | • | • | • |
| APR | 12.8 | 11.5 | 85 | 12.5 | 20.6 | 6.3 | 13.5 | 26.1 | 24 | 0.5 | 16 | 14.3 | 25.6 | 4.1 | -1.4 | 3.3 | 30 | 15 | 2 | 7 | 4 | • | • | • | • | • | 1 | • |
| MAY | 7.4 | 6.2 | 83 | 8.5 | 15.4 | 2.6 | 9.0 | 21.6 | 11 | -3.7 | 28 | 12.8 | 25.3 | 0.2 | -7.6 | 4.9 | 29 | 11 | 18 | 9 | 5 | • | • | • | • | 2 | 12 | 11 |
| JUN | 4.9 | 3.6 | 79 | 6.9 | 12.8 | 0.5 | 6.7 | 18.4 | 6 | -6.6 | 14 | 12.3 | 25.0 | -2.1 | -8.2 | 4.4 | 82 | 66 | 25 | 7 | 3 | • | 3 | 1 | • | • | 20 | 13 |
| JUL | 3.5 | 2.4 | 81 | 6.4 | 10.9 | -0.3 | 5.3 | 17.6 | 30 | -5.6 | 4 | 11.2 | 23.2 | -3.0 | -10.1 | 4.0 | 95 | 16 | 6 | 14 | 12 | 2 | 2 | • | • | • | 21 | 18 |
| AUG | 4.1 | 3.4 | 88 | 7.2 | 9.9 | 0.9 | 5.4 | 18.7 | 20 | -4.0 | 4 | 9.0 | 22.7 | -0.7 | -6.1 | 5.0 | 322 | 100 | 23 | 14 | 13 | • | 2 | • | • | • | 18 | 14 |
| SEP | 9.2 | 7.4 | 76 | 8.9 | 14.1 | 3.7 | 8.9 | 21.4 | 26 | -2.1 | 10 | 10.4 | 23.5 | 1.2 | -3.0 | 5.2 | 81 | 29 | 15 | 13 | 11 | • | • | • | • | • | 10 | 4 |
| OCT | 12.1 | 10.0 | 75 | 10.6 | 16.3 | 7.4 | 11.9 | 23.2 | 24 | 1.2 | 20 | 8.9 | 22.0 | 5.6 | -1.9 | 5.6 | 110 | 43 | 17 | 15 | 14 | • | • | • | 1 | • | 1 | • |
| NOV | 12.9 | 11.2 | 80 | 11.9 | 18.3 | 7.5 | 12.9 | 28.8 | 7 | 1.1 | 20 | 10.8 | 27.7 | 5.8 | -0.5 | 5.2 | 46 | 15 | 2 | 8 | 6 | • | • | • | • | • | • | • |
| DEC | 15.1 | 12.5 | 72 | 12.4 | 20.5 | 10.0 | 15.3 | 28.5 | 19 | 2.8 | 5 | 10.5 | 25.7 | 8.0 | 1.5 | 6.8 | 16 | 06 | 21 | 5 | 4 | • | • | 1 | 1 | • | • | • |
| YEAR | 10.9 | 9.2 | 80 | 10.8 | 17.0 | 5.9 | 11.5 | 31.8 | | -6.6 | | 11.1 | 38.4 | 3.9 | -10.1 | 5.0 | 1102 | 100 | | 122 | 95 | 2 | 7 | 2 | 2 | 3 | 83 | 60 |

DAILY TOTALS YEAR-1987 SITE- 1234 ITEM- 1 RATING NOT APPLIED

| DAY | JAN | FEB | MAR | APR | MAY | JUN | JLY | AUG | SEP | OCT | NOV | DEC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | |
| 2 | 0 | 0 | 8 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 0 | |
| 3 | 0 | 0 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 4 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 4 | |
| 6 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 6 | 0 | |
| 7 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 4 | 1 | |
| 9 | 0 | 0 | 1 | 16 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 16 | |
| 10 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | |
| 11 | 0 | 0 | 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | |
| 12 | 0 | 4 | 1 | 0 | 0 | 0 | 14 | 0 | 1 | 16 | 0 | 0 | |
| 13 | 0 | 1 | 1 | 0 | 0 | 0 | 6 | 0 | 6 | 39 | 0 | 0 | |
| 14 | 0 | 3 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 2 | 5 | 0 | |
| 15 | 0 | 10 | 0 | 2 | 0 | 6 | 5 | 0 | 8 | 0 | 0 | 0 | |
| 16 | 0 | 3 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 0 | 11 | 0 | |
| 17 | 0 | 8 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | |
| 18 | 0 | 2 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | |
| 19 | 0 | 0 | 0 | 0 | 5 | 3 | 0 | 0 | 0 | 0 | 0 | 12 | |
| 20 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 21 | 0 | 0 | 3 | 3 | 41 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | |
| 22 | 4 | 0 | 0 | 0 | 2 | 0 | 12 | 1 | 1 | 0 | 1 | 1 | |
| 23 | 0 | 3 | 2 | 9 | 0 | 0 | 5 | 1 | 0 | 0 | 39 | 2 | |
| 24 | 0 | 0 | 3 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 1 | 0 | |
| 25 | 2 | 0 | 18 | 0 | 0 | 19 | 2 | 0 | 0 | 0 | 0 | 4 | |
| 26 | 1 | 1 | 0 | 0 | 0 | 7 | 1 | 7 | 0 | 0 | 10 | ? | |
| 27 | 0 | 17 | 2 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | ? | |
| 28 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | ? | |
| 29 | 0 | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | ? | |
| 30 | 0 | | 1 | 36 | 0 | 3 | 0 | 0 | 1 | 0 | 1 | ? | |
| 31 | 0 | | 1 | | 0 | | 0 | 0 | | 0 | | ? | |
| MIN | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOT | 9 | 68 | 155 | 75 | 62 | 42 | 61 | 29 | 32 | 64 | 88 | 43 | 728 |
| MAX | 4 | 17 | 60 | 36 | 41 | 19 | 14 | 14 | 9 | 39 | 39 | 16 | 60 |
| NO>0 | 4 | 13 | 16 | 10 | 7 | 6 | 11 | 6 | 9 | 5 | 14 | 10 | 111 |

End of Process

# APPENDIX 4.2 – Flow records of gauging sites in the Cheviot region determined 1986 – 1987.

## (a) Flow records of Leamington Stream, Jed and Waiau Rivers:

DAILY MEANS   YEAR=1986   SITE= 64603   ITEM= 1   RATING APPLIED
READ TABLE: XXXX00

WAIAU AT MOUTH

| DAY | JAN | FEB | MAR | APR | MAY | JUN | JLY | AUG | SEP | OCT | NOV | DEC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 908 | 376 | 757 | 1219 | 558 | 1121 | 943 | 1918 | 1583 | 1476 | 1320 | 947 | |
| 2 | 839 | 376 | 1123 | 931 | 837 | 1265 | 800 | 2470 | 1569 | 1488 | 1225 | 884 | |
| 3 | 841 | 376 | 696 | 939 | 657 | 908 | 937 | 1792 | 1519 | 2108 | 1160 | 819 | |
| 4 | 930 | 358 | 814 | 5736 | 571 | 785 | 709 | 1476 | 1514 | 4851 | 1701 | 757 | |
| 5 | 1042 | 329 | 716 | 1111 | 1453 | 1157 | 662 | 1399 | 1432 | 4311 | 1298 | 712 | |
| 6 | 725 | 320 | 601 | 1979 | 773 | 1151 | 692 | 1278 | 1471 | 3472 | 1270 | 681 | |
| 7 | 698 | 306 | 500 | 1133 | 591 | 990 | 1108 | 1163 | 1874 | 2264 | 1317 | 663 | |
| 8 | 697 | 291 | 466 | 1312 | 573 | 796 | 2430 | 1227 | 3623 | 1862 | 1333 | 623 | |
| 9 | 700 | 296 | 412 | 1288 | 526 | 911 | 1691 | 1540 | 2183 | 1679 | 1602 | 580 | |
| 10 | 1052 | 300 | 512 | 1215 | 483 | 1025 | 1358 | 2381 | 1760 | 1694 | 1191 | 551 | |
| 11 | 963 | 285 | 1015 | 1105 | 491 | 1161 | 1315 | 8776 | 1582 | 1770 | 1034 | 545 | |
| 12 | 685 | 302 | 809 | 839 | 553 | 1358 | 1643 | 7271 | 1556 | 3429 | 973 | 537 | |
| 13 | 782 | 327 | 828 | 1030 | 488 | 1347 | 1134 | 3845 | 1569 | 3249 | 1272 | 553 | |
| 14 | 711 | 355 | 842 | 1358 | 466 | 1321 | 943 | 2889 | 1462 | 2432 | 1102 | 548 | |
| 15 | 635 | 414 | 674 | 896 | 465 | 995 | 794 | 2151 | 1699 | 2024 | 1247 | 533 | |
| 16 | 552 | 425 | 640 | 737 | 432 | 846 | 736 | 2172 | 2535 | 1799 | 1034 | 572 | |
| 17 | 853 | 682 | 549 | 648 | 443 | 719 | 715 | 1985 | 2706 | 1890 | 899 | 650 | |
| 18 | 1512 | 658 | 488 | 599 | 704 | 664 | 684 | 1869 | 2293 | 2415 | 853 | 871 | |
| 19 | 798 | 531 | 443 | 371 | 642 | 643 | 664 | 1820 | 2001 | 2119 | 795 | 652 | |
| 20 | 625 | 512 | 418 | 557 | 545 | 618 | 656 | 2109 | 1765 | 1745 | 741 | 646 | |
| 21 | 687 | 479 | 423 | 543 | 1200 | 609 | 716 | 2290 | 1953 | 1617 | 699 | 856 | |
| 22 | 1704 | 456 | 392 | 535 | 1385 | 651 | 793 | 3972 | 2009 | 2137 | 673 | 808 | |
| 23 | 1510 | 438 | 449 | 491 | 912 | 838 | 674 | 5217 | 1712 | 2560 | 656 | 945 | |
| 24 | 1369 | 434 | 427 | 447 | 712 | 758 | 650 | 9283 | 1574 | 1974 | 766 | 875 | |
| 25 | 1017 | 416 | 461 | 435 | 610 | 971 | 1183 | 1752 | 1519 | 2025 | 1312 | 967 | |
| 26 | 955 | 411 | 358 | 434 | 585 | 1842 | 4310 | 2974 | 1486 | 2002 | 1182 | 1173 | |
| 27 | 803 | 390 | 407 | 516 | 554 | 1137 | 2946 | 2291 | 1496 | 1610 | 1358 | 981 | |
| 28 | 707 | 398 | 478 | 855 | 539 | 1023 | 2040 | 1966 | 2466 | 1881 | 995 | 677 | |
| 29 | 564 | | 1387 | 870 | 526 | 1148 | 2032 | 1836 | 2142 | 1580 | 854 | 594 | |
| 30 | 464 | | 1271 | 856 | 523 | 1028 | 1863 | 1757 | 1636 | 1435 | 811 | 593 | |
| 31 | 407 | | 987 | | 1645 | | 1798 | 1603 | | 1315 | | 1313 | |
| MIN | 407 | 285 | 358 | 434 | 432 | 618 | 650 | 1163 | 1432 | 1315 | 673 | 533 | 285 |
| MEAN | 873 | 401 | 634 | 1123 | 693 | 1041 | 1270 | 2892 | 1870 | 2219 | 1097 | 754 | 1246 |
| MAX | 1910 | 682 | 1387 | 5736 | 1645 | 1842 | 4310 | 9283 | 3623 | 4851 | 1701 | 1313 | 9283 |

DAILY MEANS   YEAR=1987   SITE= 64603   ITEM= 1   RATING APPLIED
READ TABLE: XXXX00

WAIAU AT MOUTH

| DAY | JAN | FEB | MAR | APR | MAY | JUN | JLY | AUG | SEP | OCT | NOV | DEC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 920 | ? | ? | 2980 | 1733 | 3022 | 1071 | 669 | 778 | 2079 | 1233 | ? | |
| 2 | 715 | ? | ? | 1863 | 1503 | 1870 | 913 | 991 | 722 | 1931 | 979 | ? | |
| 3 | 620 | ? | ? | 1147 | 994 | 1428 | 827 | 925 | 778 | 779 | 880 | ? | |
| 4 | 551 | ? | ? | 932 | 855 | 1833 | 774 | 789 | 1330 | 694 | 773 | ? | |
| 5 | 507 | ? | ? | 804 | 1103 | 2006 | 747 | 946 | 1058 | 615 | 1061 | ? | |
| 6 | 477 | ? | ? | 744 | 931 | 1349 | 745 | 2487 | 891 | 686 | 858 | ? | |
| 7 | 460 | ? | ? | 679 | 764 | 1127 | 699 | 1590 | 717 | 1115 | 950 | ? | |
| 8 | 441 | ? | ? | 655 | 691 | 1025 | 687 | 1196 | 750 | 2496 | 791 | ? | |
| 9 | 427 | ? | ? | 681 | 619 | 937 | 737 | 1011 | 706 | 1918 | 684 | ? | |
| 10 | 419 | ? | ? | 1582 | 613 | 862 | 808 | 881 | 939 | 1189 | 679 | ? | |
| 11 | 458 | ? | ? | 1931 | 583 | 831 | 731 | 791 | 768 | 1257 | 731 | ? | |
| 12 | 444 | ? | ? | 822 | 574 | 776 | 706 | 741 | 894 | 1123 | 653 | ? | |
| 13 | 409 | ? | ? | 713 | 547 | 741 | 992 | 691 | 896 | 1256 | 642 | ? | |
| 14 | 384 | ? | ? | 700 | 524 | 768 | 1904 | 663 | 827 | 1553 | 696 | ? | |
| 15 | 539 | ? | ? | 641 | 536 | 3786 | 1531 | 612 | 784 | 1431 | 947 | ? | |
| 16 | 1806 | ? | ? | 610 | 509 | 2207 | 1312 | 624 | 700 | 1198 | 768 | ? | |
| 17 | 1056 | ? | ? | 604 | 519 | 1303 | 1048 | 615 | 660 | 1352 | ? | ? | |
| 18 | 1322 | ? | ? | 580 | 632 | 1273 | 824 | 658 | 771 | 1602 | ? | ? | |
| 19 | 1274 | ? | ? | 569 | 717 | 1126 | 779 | 698 | 668 | 1676 | ? | ? | |
| 20 | ? | ? | 940 | 561 | 917 | 1196 | 735 | 627 | 609 | 1753 | ? | ? | |
| 21 | ? | ? | 863 | 577 | 781 | 1072 | 715 | 607 | 592 | 1519 | ? | ? | |
| 22 | ? | ? | 823 | 1614 | 2309 | 970 | 702 | 594 | 620 | 1409 | ? | ? | |
| 23 | ? | ? | 811 | 1376 | 1478 | 880 | 1133 | 1327 | 775 | 1759 | ? | ? | |
| 24 | ? | ? | 750 | 1201 | 1210 | 829 | 1755 | 916 | 627 | 1304 | ? | ? | |
| 25 | ? | ? | 811 | 836 | 961 | 828 | 1145 | 689 | 605 | 1742 | ? | ? | |
| 26 | ? | ? | 949 | 745 | 878 | 1082 | 1293 | 627 | 567 | 1373 | ? | ? | |
| 27 | ? | ? | 867 | 741 | 820 | 1057 | 1111 | 865 | 553 | 1069 | ? | ? | |
| 28 | ? | ? | 755 | 691 | 783 | 966 | 895 | 1482 | 576 | 914 | ? | ? | |
| 29 | ? | | 723 | 741 | 2388 | 874 | 787 | 1183 | 554 | 997 | ? | ? | |
| 30 | ? | | 685 | 672 | 2478 | 1138 | 710 | 1125 | 552 | 2717 | ? | ? | |
| 31 | ? | | 846 | | 1954 | | 683 | 902 | | 1754 | | ? | |
| MIN | 384 | ? | 685 | 561 | 509 | 761 | 683 | 574 | 553 | 615 | 642 | ? | 384 |
| MEAN | 696 | ? | 819 | 939 | 1036 | 1319 | 930 | 958 | 739 | 1378 | 845 | ? | 994 |
| MAX | 1806 | ? | 949 | 2980 | 2478 | 3786 | 1755 | 2487 | 1330 | 2717 | 1233 | ? | 3788 |

End of process

DAILY MEANS   YEAR=1987   SITE= 64702   ITEM= 1   RATING APPLIED

JED

| DAY | JAN | FEB | MAR | APR | MAY | JUN | JLY | AUG | SEP | OCT | NOV | DEC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 15 | 43 | 335 | 52 | 178 | 238 | 131 | 54 | 21 | 33 | |
| 2 | 0 | 0 | 27 | 38 | 169 | 52 | 71 | 187 | 122 | 72 | 16 | 25 | |
| 3 | 0 | 0 | 39 | 57 | 54 | 48 | 13 | 150 | 119 | 62 | 17 | 33 | |
| 4 | 0 | 0 | 276 | 56 | 47 | 52 | 20 | 159 | 112 | 57 | 22 | 31 | |
| 5 | 0 | 0 | 190 | 56 | 60 | 50 | 14 | 301 | 62 | 61 | 19 | 18 | |
| 6 | 0 | 0 | 59 | 54 | 41 | 39 | 5 | 247 | 51 | 56 | 19 | 10 | |
| 7 | 0 | 0 | 30 | 31 | 36 | 29 | 5 | 188 | 109 | 89 | 19 | 7 | |
| 8 | 0 | 0 | 21 | 60 | 33 | 35 | 10 | 142 | 97 | 76 | 17 | 13 | |
| 9 | 0 | 0 | 16 | 61 | 47 | 46 | 22 | 108 | 109 | 41 | 22 | 19 | |
| 10 | 0 | 0 | 17 | 160 | 69 | 41 | 8 | 103 | 105 | 43 | 27 | ? | |
| 11 | 0 | 0 | 34 | 187 | 79 | 31 | 11 | 106 | 124 | 45 | 22 | ? | |
| 12 | 0 | 0 | 379 | 89 | 57 | 46 | 15 | 85 | 115 | 40 | 17 | ? | |
| 13 | 0 | 0 | 342 | 59 | 69 | 84 | 1975 | 62 | 96 | 892 | 15 | ? | |
| 14 | 0 | 0 | 132 | 46 | 54 | 68 | 1020 | 43 | 141 | 1145 | 12 | ? | |
| 15 | 0 | 1 | 74 | 11 | 15 | 48 | 2142 | 39 | 195 | 330 | 8 | ? | |
| 16 | 0 | 6 | 43 | 27 | 65 | 64 | 827 | 52 | 376 | 115 | 8 | ? | |
| 17 | 0 | 18 | 30 | 21 | 79 | 61 | 479 | 56 | 237 | 53 | 43 | ? | |
| 18 | 0 | 14 | 22 | 21 | 115 | 55 | 252 | 59 | 152 | 39 | 27 | ? | |
| 19 | 0 | 19 | 23 | 21 | 190 | 61 | 183 | 11 | 103 | 31 | 14 | ? | |
| 20 | 0 | 9 | 19 | 33 | 201 | 42 | 163 | 35 | 80 | 31 | 16 | ? | |
| 21 | 0 | 7 | 17 | 39 | 549 | 30 | 121 | 57 | 69 | 29 | 16 | ? | |
| 22 | 0 | 10 | 16 | 65 | 2030 | 20 | 104 | 59 | 69 | 29 | 22 | ? | |
| 23 | 0 | 8 | 18 | 65 | 601 | 73 | 705 | 70 | 73 | 20 | 29 | ? | |
| 24 | 0 | 7 | 24 | 67 | 331 | 24 | 831 | 77 | 78 | 21 | 615 | ? | |
| 25 | 0 | 8 | 18 | 61 | 214 | 55 | 517 | 90 | 44 | 17 | 271 | ? | |
| 26 | 0 | 8 | 184 | 63 | 172 | 509 | 518 | 81 | 37 | 23 | 115 | ? | |
| 27 | 0 | 4 | 111 | 50 | 138 | 403 | 633 | 208 | 46 | 24 | 175 | ? | |
| 28 | 0 | 7 | 67 | 54 | 109 | 181 | 364 | 1310 | 58 | 28 | 52 | ? | |
| 29 | 0 | | 13 | 64 | 82 | 127 | 263 | 457 | 36 | 26 | 71 | ? | |
| 30 | 0 | | 56 | 76 | 79 | 95 | 206 | 256 | 50 | 17 | 36 | ? | |
| 31 | 0 | | 44 | | 70 | | 181 | 171 | | 19 | | ? | |
| MIN | 0 | 0 | 15 | 21 | 33 | 20 | 5 | 35 | 36 | 17 | 8 | 7 | 0 |
| MEAN | 0 | 1 | 79 | 60 | 201 | 82 | 392 | 170 | 108 | 116 | 57 | 21 | 114 |
| MAX | 0 | 19 | 379 | 187 | 2030 | 509 | 2142 | 1310 | 376 | 1145 | 615 | 33 | 2142 |

End of process

*** MICRO-TIDEDA *** VERSION 3.0   NORTH CANTERBURY CATCHMENT BOARD
*** FDAY ***   VER 1.4   25-07-83

DAILY MEANS   YEAR=1986   SITE= 64702   ITEM= 1   RATING APPLIED

JED

| DAY | JAN | FEB | MAR | APR | MAY | JUN | JLY | AUG | SEP | OCT | NOV | DEC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 131 | 45 | |
| 2 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 108 | 46 | |
| 3 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 202 | 32 | |
| 4 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 210 | 27 | |
| 5 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 162 | 19 | |
| 6 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 133 | 15 | |
| 7 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 128 | 26 | |
| 8 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 114 | 20 | |
| 9 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 79 | 10 | |
| 10 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 61 | 5 | |
| 11 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 57 | 5 | |
| 12 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 53 | 7 | |
| 13 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 50 | 13 | |
| 14 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 48 | 30 | |
| 15 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 28 | 20 | |
| 16 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 27 | 11 | |
| 17 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 31 | 14 | |
| 18 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 31 | 8 | |
| 19 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 47 | 8 | |
| 20 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 38 | 3 | |
| 21 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 33 | 8 | |
| 22 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 40 | 21 | |
| 23 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 53 | 20 | |
| 24 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 50 | 10 | |
| 25 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 36 | 4 | |
| 26 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 46 | 0 | |
| 27 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 60 | 0 | |
| 28 | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 59 | 0 | |
| 29 | ? | | ? | ? | ? | ? | ? | ? | ? | ? | 20 | 0 | |
| 30 | ? | | ? | ? | ? | ? | ? | ? | ? | ? | 11 | 0 | |
| 31 | ? | | ? | | ? | | ? | ? | | ? | | 0 | |
| MIN | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 11 | 0 | 0 |
| MEAN | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 71 | 14 | 42 |
| MAX | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | 210 | 46 | 210 |

End of process

DAILY MEANS YEAR-1986 SITE- 61409 ITEM- 1 RATING APPLIED
READ TABLE! XXXX0

LEAMINGTON AT MT PALM TRACK

| DAY | JAN | FEB | MAR | APR | MAY | JUN | JLY | AUG | SEP | OCT | NOV | DEC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 18 | 3 | 17 | 91 | 4 | 5 | 62 | 60 | 96 | 50 | 32 | 30 | |
| 2 | 18 | 3 | 12 | 74 | 4 | 3 | 57 | 50 | 89 | 45 | 31 | 26 | |
| 3 | 16 | 4 | 10 | 121 | 4 | 3 | 129 | 42 | 101 | 39 | 111 | 24 | |
| 4 | 15 | 4 | 11 | 82 | 5 | 4 | 85 | 32 | 101 | 40 | 58 | 18 | |
| 5 | 9 | 3 | 9 | 61 | 4 | 1 | 74 | 35 | 76 | 42 | 43 | 12 | |
| 6 | 9 | 3 | 7 | 78 | 3 | 4 | 124 | 30 | 68 | 35 | 36 | 13 | |
| 7 | 12 | 3 | 7 | 50 | 3 | 3 | 779 | 28 | 68 | 38 | 29 | 14 | |
| 8 | 14 | 3 | 5 | 38 | 3 | 3 | 1140 | 54 | 58 | 41 | 24 | 10 | |
| 9 | 18 | 3 | 1 | 31 | 4 | 3 | 139 | 208 | 56 | 63 | 19 | 8 | |
| 10 | 16 | 3 | 3 | 23 | 4 | 3 | 450 | 994 | 50 | 61 | 18 | 6 | |
| 11 | 12 | 3 | 3 | 21 | 1 | 3 | 197 | 2869 | 48 | 790 | 19 | 7 | |
| 12 | 12 | 3 | 4 | 21 | 1 | 3 | 533 | 1132 | 44 | 733 | 20 | 6 | |
| 13 | 10 | 4 | 29 | 20 | 3 | 3 | 266 | 681 | 40 | 351 | 18 | 10 | |
| 14 | 7 | 15 | 30 | 14 | 3 | 3 | 165 | 399 | 42 | 208 | 13 | 9 | |
| 15 | 6 | 19 | 21 | 15 | 1 | 3 | 121 | 318 | 108 | 118 | 14 | 8 | |
| 16 | 5 | 12 | 19 | 10 | 3 | 3 | 101 | 247 | 756 | 112 | 16 | 5 | |
| 17 | 3 | 23 | 13 | 6 | 3 | 1 | 96 | 202 | 686 | 87 | 17 | 8 | |
| 18 | 4 | 22 | 9 | 6 | 4 | 4 | 69 | 174 | 438 | 586 | 15 | 10 | |
| 19 | 3 | 13 | 9 | 5 | 4 | 3 | 43 | 156 | 268 | 221 | 17 | 8 | |
| 20 | 3 | 8 | 7 | 6 | 7 | 4 | 39 | 137 | 213 | 161 | 17 | 9 | |
| 21 | 3 | 4 | 9 | 6 | 5 | 6 | 94 | 175 | 344 | 118 | 16 | 7 | |
| 22 | 3 | 3 | 10 | 6 | 5 | 7 | 104 | 1235 | 270 | 114 | 20 | 8 | |
| 23 | 4 | 3 | 9 | 5 | 1 | 6 | 72 | 1978 | 196 | 105 | 19 | 9 | |
| 24 | 22 | 3 | 12 | 4 | 4 | 6 | 65 | 2807 | 146 | 75 | 16 | 7 | |
| 25 | 15 | 32 | 13 | 1 | 3 | 10 | 92 | 916 | 111 | 63 | 21 | 4 | |
| 26 | 6 | 30 | 14 | 5 | 4 | 606 | 168 | 501 | 90 | 52 | 62 | 3 | |
| 27 | 5 | 21 | 12 | 5 | 1 | 193 | 119 | 300 | 77 | 47 | 55 | 4 | |
| 28 | 16 | 18 | 8 | 4 | 4 | 100 | 98 | 203 | 65 | 45 | 36 | 5 | |
| 29 | 13 | | 13 | 1 | 4 | 89 | 80 | 177 | 72 | 40 | 26 | 4 | |
| 30 | 5 | | 20 | 4 | 4 | 68 | 73 | 143 | 55 | 35 | 21 | 3 | |
| 31 | 4 | | 82 | | 5 | | 64 | 115 | | 32 | | 2 | |
| MIN | 3 | 3 | 3 | 4 | 3 | 3 | 39 | 28 | 40 | 32 | 13 | 2 | 2 |
| MEAN | 10 | 10 | 14 | 27 | 4 | 48 | 204 | 326 | 171 | 135 | 29 | 10 | 99 |
| MAX | 22 | 32 | 82 | 121 | 7 | 606 | 1140 | 2869 | 756 | 733 | 111 | 30 | 2869 |

DAILY MEANS YEAR-1987 SITE- 61409 ITEM- 1 RATING APPLIED

LEAMINGTON AT MT PALM TRACK

| DAY | JAN | FEB | MAR | APR | MAY | JUN | JLY | AUG | SEP | OCT | NOV | DEC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 44 | 2 | 22 | 221 | 1181 | 401 | 597 | 815 | 730 | 401 | 74 | 314 | |
| 2 | 37 | 1 | 20 | 221 | 665 | 306 | 399 | 575 | 640 | 92 | 79 | 295 | |
| 3 | 32 | 5 | 2689 | 178 | 475 | 312 | 412 | 378 | 591 | 119 | 67 | 294 | |
| 4 | 14 | 4 | 9175 | 151 | 425 | 317 | 297 | 532 | 526 | 111 | 69 | 281 | |
| 5 | 9 | 3 | 2410 | 136 | 376 | 261 | 199 | 261 | 385 | 91 | 65 | 224 | |
| 6 | 9 | 3 | 1180 | 155 | 263 | 190 | 129 | 523 | 349 | 79 | 60 | 204 | |
| 7 | 9 | 3 | 691 | 168 | 192 | 215 | 143 | 418 | 287 | 82 | 74 | 205 | |
| 8 | 6 | 1 | 494 | 148 | 150 | 210 | 192 | 403 | 261 | 88 | 123 | 214 | |
| 9 | 5 | 1 | 387 | 145 | 119 | 172 | 158 | 339 | 279 | 66 | 93 | 205 | |
| 10 | 4 | 2 | 306 | 195 | 107 | 168 | 113 | 323 | 373 | 60 | 78 | ? | |
| 11 | 5 | 3 | 1951 | 289 | 118 | 111 | 135 | 309 | 266 | 60 | 91 | ? | |
| 12 | 7 | 3 | 9659 | 231 | 115 | 83 | 153 | 293 | 282 | 59 | 96 | ? | |
| 13 | 6 | 1 | 3270 | 180 | 121 | 85 | 2500 | 217 | 276 | 371 | 95 | ? | |
| 14 | 3 | 1 | 1526 | 173 | 87 | 84 | 2900 | 211 | 374 | 825 | 91 | ? | |
| 15 | 2 | 1 | 990 | 165 | 71 | 100 | 7765 | 213 | 301 | 118 | 82 | ? | |
| 16 | 1 | 1 | 687 | 123 | 95 | 153 | 3749 | 204 | 677 | 309 | 176 | ? | |
| 17 | 1 | 1 | 523 | 95 | 138 | 146 | 2011 | 227 | 377 | 311 | 296 | ? | |
| 18 | 1 | 1 | 423 | 99 | 176 | 112 | 1430 | 201 | 278 | 248 | 293 | ? | |
| 19 | 2 | 1 | 376 | 97 | 272 | 96 | 1095 | 211 | 202 | 275 | 261 | ? | |
| 20 | 3 | 1 | 363 | 117 | 499 | 117 | 914 | 191 | 190 | 159 | 159 | ? | |
| 21 | 3 | 1 | 327 | 143 | 835 | 93 | 760 | 221 | 211 | 479 | 158 | ? | |
| 22 | 5 | 1 | 315 | 163 | 9262 | 69 | 662 | 193 | 157 | 111 | 177 | ? | |
| 23 | 1 | 1 | 279 | 198 | 3193 | 66 | 2148 | 241 | 175 | 59 | 171 | ? | |
| 24 | 3 | 1 | 269 | 368 | 1595 | 87 | 2477 | 239 | 149 | 103 | 348 | ? | |
| 25 | 5 | 1 | 300 | 273 | 1289 | 136 | 1797 | 215 | 132 | 95 | 630 | ? | |
| 26 | 5 | 1 | 453 | 234 | 976 | 669 | 2473 | 207 | 114 | 74 | 664 | ? | |
| 27 | 5 | 1 | 296 | 191 | 717 | 1079 | 1868 | 703 | 112 | 81 | 541 | ? | |
| 28 | 6 | 1 | 258 | 164 | 673 | 782 | 1393 | 3691 | 127 | 86 | 353 | ? | |
| 29 | 3 | | 311 | 137 | 643 | 696 | 1055 | 2263 | 105 | 111 | 324 | ? | |
| 30 | 2 | | 250 | 148 | 498 | 634 | 778 | 1489 | 120 | 85 | 330 | ? | |
| 31 | 1 | | 245 | | 186 | | 693 | 895 | | 79 | | ? | |
| MIN | 1 | 1 | 20 | 95 | 71 | 66 | 113 | 191 | 105 | 57 | 60 | 204 | 1 |
| MEAN | 8 | 2 | 1712 | 178 | 950 | 246 | 1363 | 577 | 306 | 140 | 201 | 219 | 476 |
| MAX | 44 | 5 | 9659 | 368 | 9262 | 1079 | 7765 | 3691 | 735 | 825 | 664 | 314 | 9659 |

End of process

## (b) Flow records of selected gauging sites in the Spotswood and Mina areas:

GAUGING SITE NUMBER

Values in litres per second

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25.11.86 | 10 | 26 | 140 | 9 | 96 | 0 | 87 | 0 | 0 | 0 | 2 | 9 | 0 | 0 | 66 | 39 | 29 | 16 | 14 | 74 | 96 | 109 | 9 | 66 |
| 16.12.86 | 6 | 10 | 138 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 23 | 6 | 65 | 73 | 117 | 7 | 48 |
| 13.01.87 | 0 | 0 | 13 | 0 | 4 | 0 | 10 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 9 | 11 | 5 | 13 | 5 | 32 | 72 | 113 | 0 | 41 |
| 12.02.87 | 0 | 0 | 121 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 6 | 4 | 30 | 10 | 57 | 76 | 139 | 3 | 53 |
| 19.03.87 | 20 | 33 | 180 | 25 | 326 | 265 | 379 | 0 | 148 | 0 | 3 | 13 | 7 | 16 | 326 | 142 | 157 | 22 | 8 | 85 | 83 | 141 | 7 | 50 |
| 15.04.87 | 9 | 28 | 150 | 10 | 82 | 0 | 69 | 0 | 24 | 0 | 6 | 10 | 0 | 6 | 63 | 38 | 44 | 34 | 9 | 110 | 94 | 155 | 8 | 62 |
| 14.05.87 | 0 | 0 | 0 | 6 | 0 | 0 | 93 | 0 | 0 | 20 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 22 | 8 | 59 | 88 | 131 | 0 | 47 |
| 16.06.87 | * | * | * | 61 | * | 39 | 192 | * | * | 53 | * | * | * | 61 | * | * | * | 24 | 7 | 61 | 125 | 153 | 6 | 82 |
| 16.07.87 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | 24 | 6 | 67 | 132 | 157 | 13 | 73 |
| 14.08.87 | * | * | * | 21 | * | 68 | 195 | * | * | 56 | * | * | 6 | 21 | * | * | * | 27 | 9 | 53 | 150 | 167 | 24 | 97 |
| 11.09.87 | * | * | * | 42 | * | 121 | 139 | 42 | * | * | * | * | 16 | 42 | * | * | * | 22 | 8 | 55 | 128 | 169 | 18 | 123 |

APPENDIX 4.3 - Water levels recorded in bores in the Spotswood and Mina plains.

(a) Mina Plains.

| | BORE REFERENCE (water levels in millimetres x10) | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N33 | | O33 | | | | | | | | | | | | | | | | | | |
| DATE | 8 | 91 | 172 | 174 | 175 | 11 | 26 | 20 | 46 | 47 | 59 | 50 | 58 | 61 | 62 | 63 | 56 | 64 | 65 | 69 | 73 |
| 16.12.86 | | | | | | 233 | | | 206 | 62 | 188 | | 412 | 275 | | | 249 | | | | |
| 13.1.87 | | | | | | 248 | | | 225 | 74 | 246 | | 448 | 318 | | | 277 | | | | |
| 20.2.87 | 235 | 654 | | | | 261 | 110 | 489 | 257 | 80 | 279 | 115 | 493 | 358 | | | 300 | | | | |
| 20.3.87 | 226 | 435 | | | | 217 | 99 | 462 | 273 | 65 | 223 | 96 | 467 | 319 | | | 286 | | | | |
| 16.4.87 | 229 | 457 | | | | 251 | 97 | 457 | 286 | 61 | 226 | | 461 | 321 | | | 283 | | | | |
| 15.5.87 | 232 | 450 | | | 550 | 282 | 1010 | 450 | 290 | 64 | 211 | | 457 | 310 | | | 282 | | | | |
| 11.6.87 | 233 | 425 | 279 | 253 | 566 | 291 | 95 | 436 | 292 | 64 | 197 | | 443 | 293 | 65 | 305 | 270 | | 182 | 157 | 236 |
| 10.7.87 | 236 | 442 | 274 | 249 | 574 | 284 | 83 | 418 | 295 | 57 | 172 | | 434 | 283 | 65 | 283 | 260 | 447 | 176 | 133 | |
| 7.8.87 | 185 | 420 | 259 | 227 | 557 | 278 | 64 | 386 | 27[illegible] | 37 | 141 | 72 | 401 | 228 | 65 | 262 | 254 | 427 | 148 | 113 | 220 |
| 16.9.87 | | 465 | 264 | 232 | 555 | 237 | 62 | 389 | 281 | 38 | 143 | 75 | 403 | 234 | | 280 | 235 | | | 175 | |
| 15.10.87 | | 517 | 268 | | 566 | 230 | 71 | 406 | 290 | 41 | 158 | 82 | 418 | 258 | | | 239 | | | | |
| 17.11.87 | | 522 | 273 | | 569 | 227 | 81 | 412 | 292 | 49 | 172 | 98 | 426 | 265 | | | 242 | | | | |

(b) Spotswood Plains.

| | BORE REFERENCE (water levels in millimetres, x10) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N32 | | N33 | | | | | N32 | | O33 | | | | |
| DATE | 13 | 61 | 81 | 86 | 112 | 163 | 166 | 17 | 19 | 20 | 22 | 3 | 36 | 42 |
| 16.12.86 | 427 | 336 | 239 | 1283 | 66 | 1052 | 287 | 152 | 116 | 115 | | 43 | 20 | 204 |
| 13.1.87 | 469 | 382 | 259 | 1311 | 278 | 1089 | 562 | 157 | 120 | 112 | | 53 | 52 | 214 |
| 20.2.87 | 394 | 313 | 225 | 1330 | 287 | 1160 | 730 | 153 | 113 | 115 | 192 | 39 | 116 | 218 |
| 20.3.87 | 320 | 299 | 167 | 1348 | 99 | 1183 | 290 | 139 | 102 | 119 | 213 | 17 | 153 | 203 |
| 16.4.87 | 340 | 259 | 196 | 1344 | 65 | 1132 | 277 | 146 | 100 | 122 | 173 | 30 | 179 | 199 |
| 15.5.87 | 379 | 292 | 209 | 1338 | 63 | 1112 | 264 | 148 | 101 | 104 | 175 | 30 | 282 | 201 |
| 11.6.87 | 300 | 250 | 182 | 1340 | 32 | 1088 | 267 | 142 | 114 | 121 | 166 | 29 | 183 | 196 |
| 10.7.87 | 376 | 288 | 202 | 1334 | 39 | 1087 | 255 | 146 | 100 | 122 | 174 | 27 | 215 | 194 |
| 7.8.87 | 280 | 276 | 179 | 1317 | 29 | 1071 | 255 | 136 | 100 | 118 | 154 | 17 | 72 | 168 |
| 16.9.87 | | 266 | 200 | 1316 | 35 | 1069 | 260 | 134 | 145 | 122 | 165 | 25 | 46 | 183 |
| 15.10.87 | | 262 | 189 | 1334 | 60 | 1079 | 288 | | | | | | | |
| 17.11.87 | | 266 | 182 | 1337 | 63 | 1081 | 290 | 141 | | | | | | |

APPENDIX 4·3

SUMMARY DATA - Heights above mean sea level of borehole datums.

i) MINA PLAINS

| REFERENCE SITE | February 1987 | August 1987 |
|---|---|---|
| N33·8 | 72·9 | 73·6 |
| ·91 | 68·6 | 70·9 |
| ·172 | – | 69·2 |
| ·174 | – | 75·7 |
| ·175 | – | 64·3 |
| 033·11 | 61·5 | 64·1 |
| ·20 | 57·7 | 68·7 |
| ·26 | 60·4 | 61·5 |
| ·46 | 61·3 | 63·9 |
| ·47 | 59·5 | 60·3 |
| ·50 | 58·1 | 59·2 |
| ·56 | 58·4 | 58·9 |
| ·58 | 58·4 | 59·3 |
| ·59 | 57·0 | 58·4 |
| ·61 | 57·7 | 59·0 |
| ·62 | | 59·5 |
| ·63 | | 62·1 |
| ·64 | | — |
| ·65 | | 63·3 |
| ·69 | | 61·2 |
| ·71 | | – |
| ·73 | | 62·9 |

| REFERENCE SITE | February 1987 | August 1987 |
|---|---|---|
| N32·13 | 40·3 | 40·6 |
| ·61 | 38·9 | 40·3 |
| ·81 | 37·5 | 38·0 |
| ·82 | – | – |
| ·83 | – | – |
| ·86 | 45·7 | 45·9 |
| ·112 | 39·5 | 42·1 |
| ·163 | 43·1 | 44·0 |
| ·166 | 46·3 | 51·0 |
| 032·17 | 28·3 | 28·4 |
| ·19 | 29·7 | 29·9 |
| ·20 | 27·6 | 27·6 |
| ·22 | 33·6 | 33·9 |
| ·3 | 30·1 | 30·3 |
| ·36 | 44·9 | 45·3 |
| ·42 | 20·3 | 20·8 |

SPOTSWOOD PLAINS:

APPENDIX 4.4 – Calculations used in the determination of total recharge/discharge from flow nets.

FLOW EQUATIONS

(1) $Q = T \times i \times W$

(2) $Q = T \times i \times l \times \sin\theta$

where
$Q$ = total flow ($m^3/min$)
$T$ = Transmissivity (average value from pump tests 1 & 2)
$i$ = hydraulic gradient
$l$ = length of river recharge reach
$W$ = width of flow line (metres)
$\sin\theta$ = angle of groundwater flow lines make with the river bank

TOTAL FLOW AS RECHARGE

Flow tube 1:

$$Q = T \times i \times l \times \sin\theta$$
$$Q_1 = 4.56 \times \frac{4}{1730} \times 2040 \times \sin 70^\circ$$
$$Q_1 = 19.2 \ m^3/min$$

Flow tube 2:

$$Q = T \times i \times W$$
$$Q_2 = 4.56 \times \frac{1}{380} \times 220$$
$$Q_2 = 2.64 \ m^3/min$$

Flow tube 3:

$$Q = T \times i \times l \times \sin\theta$$
$$Q_3 = 4.56 \times \frac{4}{860} \times 860 \times \sin 72^\circ$$
$$Q_3 = 16.5 \ m^3/min$$

TOTAL FLOW SOUTH OF LEAMINGTON STREAM

Flow tube 1 :
$$Q = T \times i \times l \times \sin\theta$$
$$Q_1 = 4{\cdot}56 \times \frac{4}{960} \times 2060 \times \sin 60^\circ$$
$$Q_1 = 31{\cdot}66 \ m^3/min$$

Flow tube 2:
$$Q_2 = T \times i \times W$$
$$Q_2 = 4{\cdot}49 \times \frac{1}{340} \times 240$$
$$Q_2 = 3{\cdot}17 \ m^3/min$$

Flow tube 3:
$$Q = T \times i \times l \times \sin\theta$$
$$Q_3 = 4{\cdot}56 \times \frac{2}{480} \times 680 \times \sin 82^\circ$$
$$Q_3 = 12{\cdot}4 \ m^3/min$$

Total flow as recharge $= Q_1 + Q_2 + Q_3$

$$Q_{tot} = 31{\cdot}66 + 3{\cdot}27 + 12{\cdot}4 = 47{\cdot}33 \ m^3/min$$

TOTAL FLOW AS DISCHARGE

Flow tube 1 :
$$Q = T \times i \times l \times \sin\theta$$
$$Q_1 = 4{\cdot}56 \times \frac{2}{680} \times 1940 \times \sin 60^\circ$$
$$Q_1 = 21{\cdot}05 \ m^3/min$$

Flow tube 2:
$$Q = T \times i \times l \times \sin\theta$$
$$Q_2 = 4{\cdot}56 \times \frac{2}{600} \times 400 \times \sin 46^\circ$$
$$Q_2 = 4{\cdot}02 \ m^3/min$$

Flow tube 3 : $Q = T \times i \times l \times \sin\theta$

$$Q_3 = 4{\cdot}56 \times \frac{1}{380} \times 480 \times \sin 45°$$

$$Q_3 = 3{\cdot}74 \ m^3/min$$

Total flow as dischage as subsurface flow

$$Q_{tot} = 21{\cdot}05 + 4{\cdot}02 + 3{\cdot}74 = 28{\cdot}81 \ m^3/min$$

Total dischage from springs and artesian bores estimated at $Q = 18{\cdot}40 \ m^3/min$. This value based on an estimate of flow from bore 033·3 (artesian) and measured flow of Willow and Awanui Springs (reference numbers 033·39 and 033·45 respectively see Appendix 4·2)

Net difference $Q_{total}$ (recharge) − $Q_{total}$ (dischage)

$$Q_{net} \Rightarrow 47{\cdot}33 - 46{\cdot}51 \ m^3/min$$

$$Q_{net} = 0{\cdot}82 \ m^3/min .$$

MINA PLAINS.

APPENDIX 4.4 – Calculations used in the detemination of total recharge / discharge from flow nets

FLOW equations

(1) $Q = T \times i \times W$

(2) $Q = T \times i \times l \times \sin\theta$

where
$Q$ = total flow ($m^3/min$)
$T$ = Transmissivity (obtained from pump test 3)
$i$ = hydraulic gradient
$l$ = length of river recharge reach
$W$ = width of flow line (metres)
$\sin\theta$ = angle of groundwater flow lines make with the river bank.

Total flow as recharge:

Flow tube 1:
$$Q = T \times i \times W$$
$$Q_1 = 0.042 \times \frac{6}{800} \times 320$$
$$Q_1 = 0.104 \ m^3/min$$

Flow tube 2:
$$Q = T \times i \times W$$
$$Q_2 = 0.042 \times \frac{2}{270} \times 270$$
$$Q_2 = 0.084 \ m^3/min$$

Flow tube 3:
$$Q = T \times i \times l \times \sin\theta$$
$$Q_3 = 0.04 \times \frac{4}{490} \times 520 \times \sin 38^\circ$$
$$Q_3 = 0.095 \ m^3/min$$

Flow tube 4 :

$$Q = T \times i \times l \times \sin\theta$$

$$Q_4 = 0.04 \times \frac{4}{470} \times 520 \times \sin 37^\circ$$

$$Q_4 = 0.097 \ m^3/min$$

Flow tube 5 :

$$Q = T \times i \times l \times \sin\theta$$

$$Q_5 = 0.04 \times \frac{10.2}{1120} \times 1300 \times \sin 40^\circ$$

$$Q_5 = 0.278 \ m^3/min$$

Flow tube 6 :

$$Q = T \times i \times l \times \sin\theta$$

$$Q_6 = 0.04 \times \frac{4}{1050} \times 1200 \times \sin 34^\circ$$

$$Q_6 = 0.093 \ m^3/min$$

Flow tube 7 :

$$Q = T \times i \times l \times \sin\theta$$

$$Q_6 = 0.04 \times \frac{2}{390} \times 400 \times \sin 31^\circ$$

$$Q_6 = 0.064 \ m^3/min$$

Total flow as recharge $= Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6$

$$Q_{tot} = 0.104 + 0.084 + 0.095 + 0.097 + 0.278 + 0.093 + 0.064$$

$$Q_{tot} = 0.815 \ m^3/min$$

Total flow as dischage :

Flow tube 1 :

$$Q = TiW$$

$$Q_1 = 0.042 \times \frac{6}{800} \times 320$$

$$Q_1 = 0.104 \ m^3/min$$

Flow tube 6 : $Q = T \times i \times l \times \sin \theta$

$$Q_6 = 0.04 \times \frac{2}{910} \times 720 \times \sin 30^\circ$$

$$Q_6 = 0.029 \ m^3/min$$

Flow tube 7 : $Q = T \times i \times l \times \sin \theta$

$$Q_7 = 0.04 \times \frac{2}{600} \times 440 \times \sin 60^\circ$$

$$Q_7 = 0.047 \ m^3/min$$

Total flow as discharge as subsurface flow

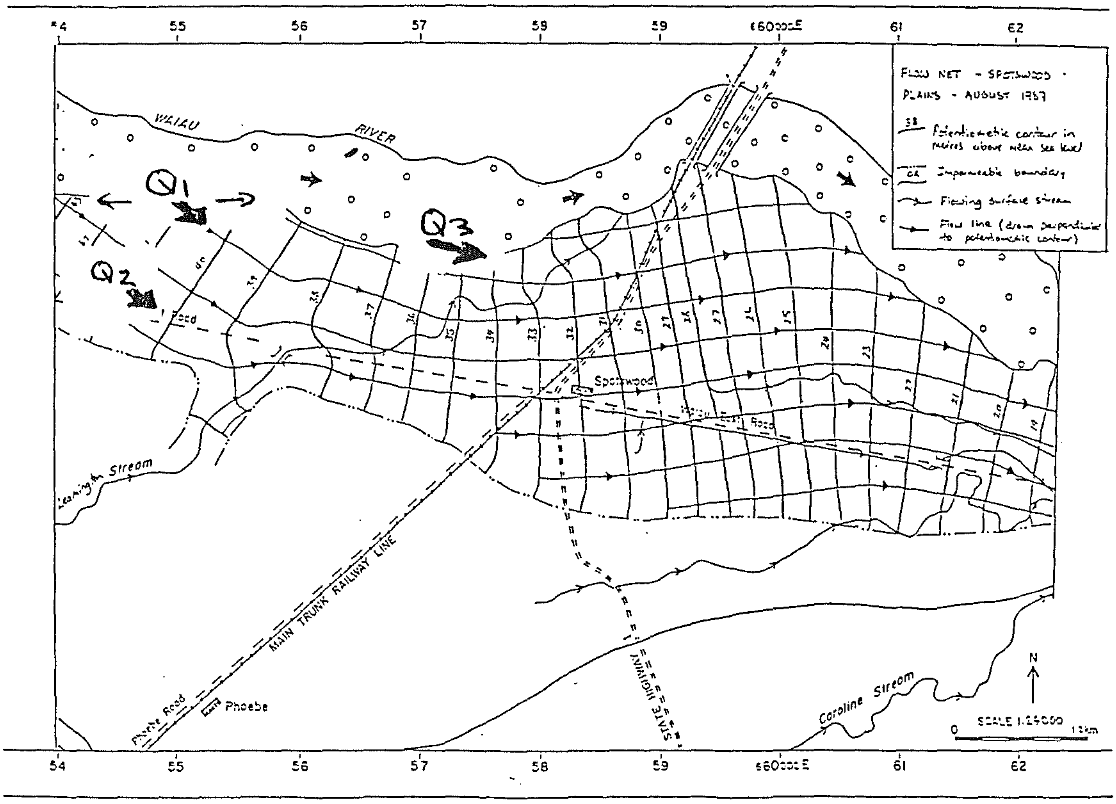
$$Q_{tot} = 0.104 + 0.029 + 0.047 = 0.18 \ m^3/min$$

Total discharge from springs and artesian bores estimated at $Q = 2.00 \ m^3/min$

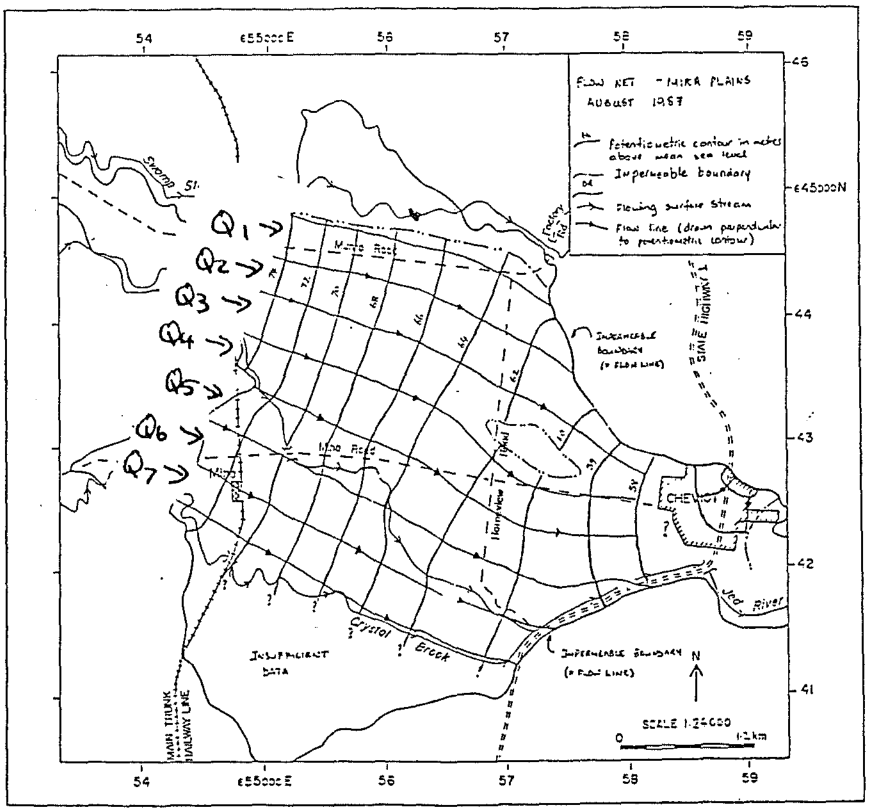
Net difference $Q_{total}$ (recharge) $- Q_{total}$ (discharge)

$$Q_{net} \Rightarrow 0.815 - 2.18 \ m^3/min$$

$$Q_{net} = -1.37 \ m^3/min$$

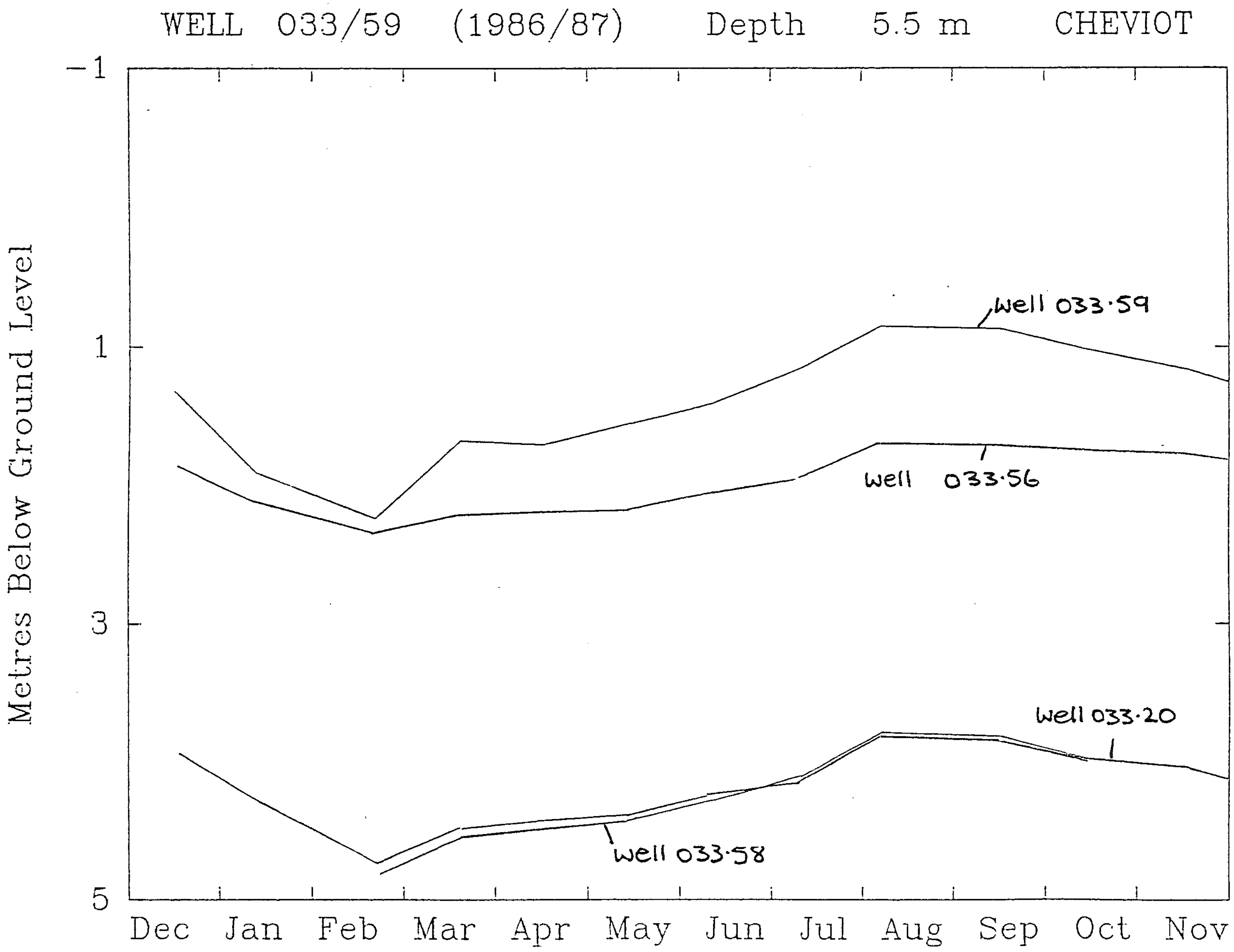


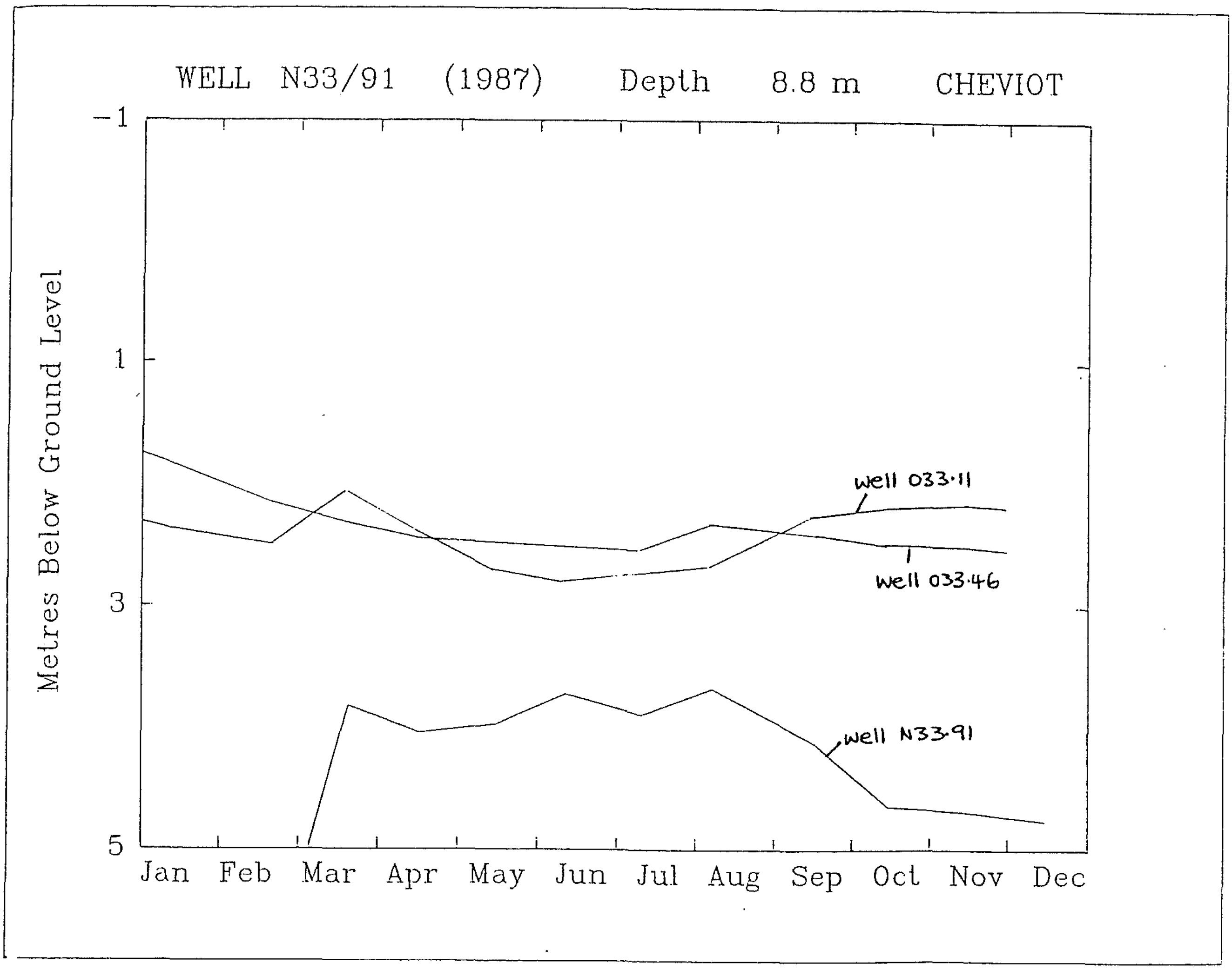
Flow net - Spotswood - Plains - August 1987
Potentiometric contour in metres above mean sea level
Impermeable boundary
Flowing surface stream
Flow line (drawn perpendicular to potentiometric contour)
Waiau River
Q1
Q2
Q3
Spotswood
Leamington Stream
Main Trunk Railway Line
State Highway 1
Phoebe Road
Phoebe
Caroline Stream
Scale 1:24000
N
e60000E

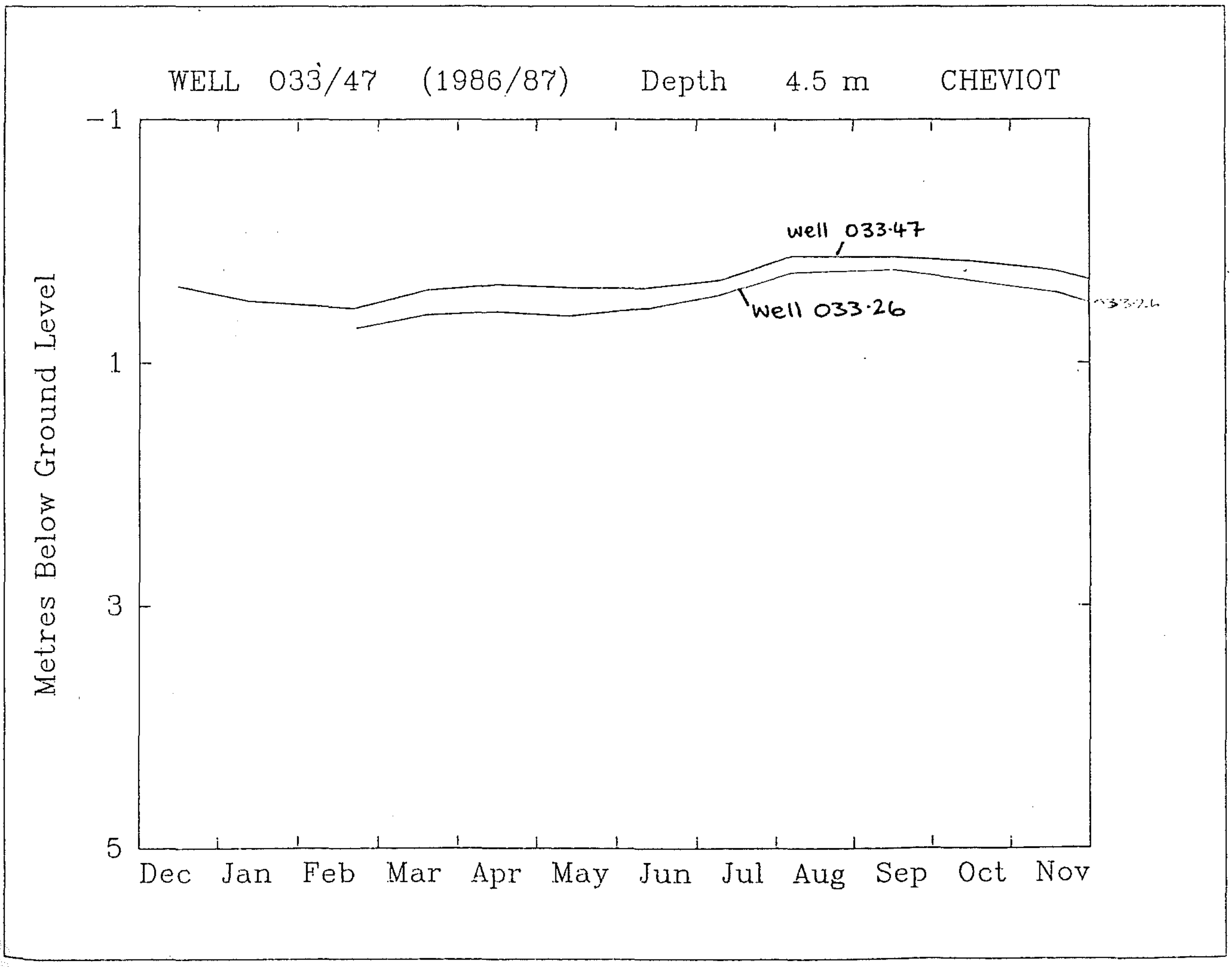



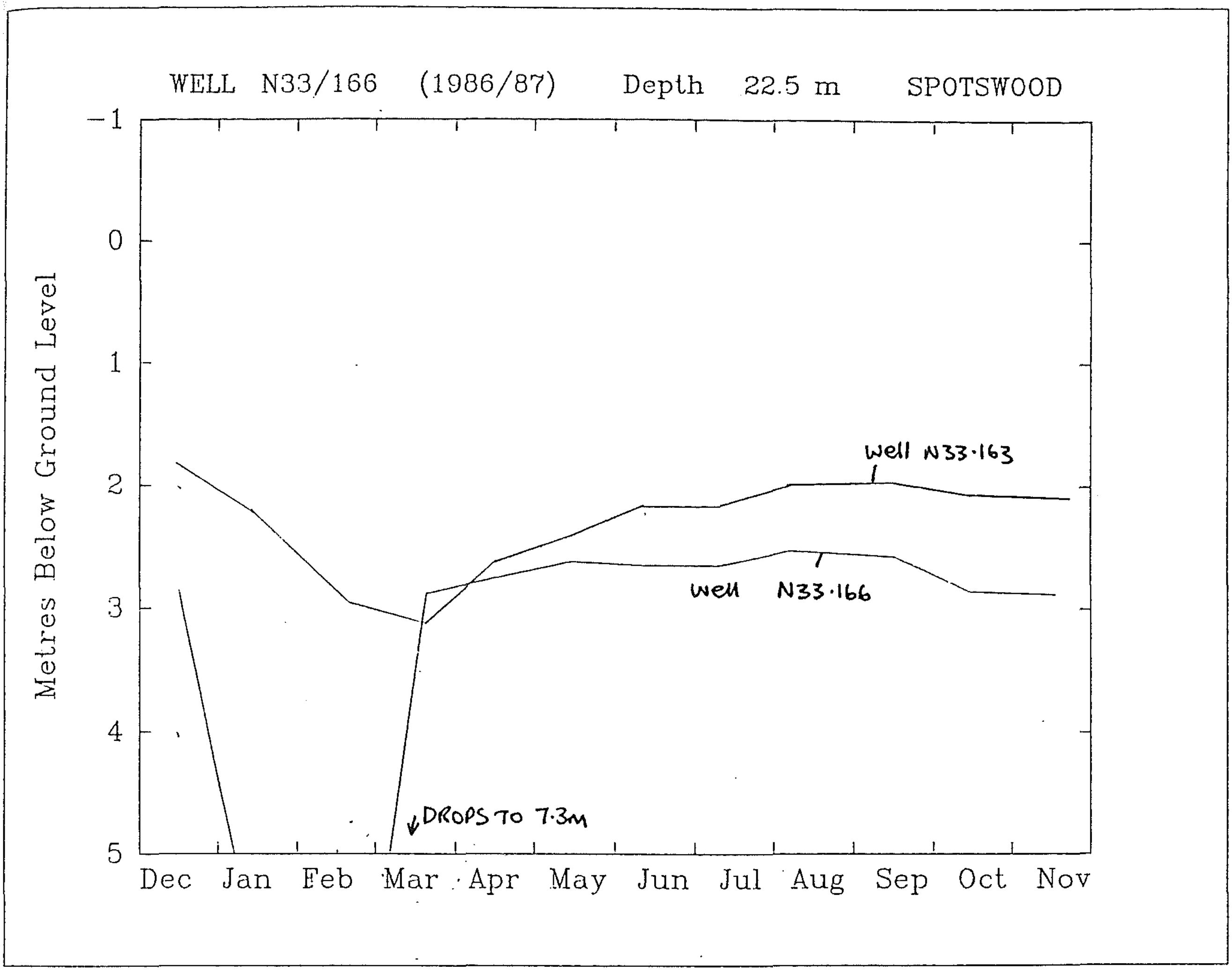
Flow net - Mira Plains August 1987
Potentiometric contour in metres above mean sea level
Impermeable boundary
Flowing surface stream
Flow line (drawn perpendicular to potentiometric contour)
Swamp St.
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Mira Road
Impermeable boundary (= flow line)
State Highway 1
Cheviot
Jed River
Crystal Brook
Insufficient data
Main Trunk Railway Line
Scale 1:24000
N
e55000E
e45000N

APPENDIX 4.5 : Water level hydrographs -

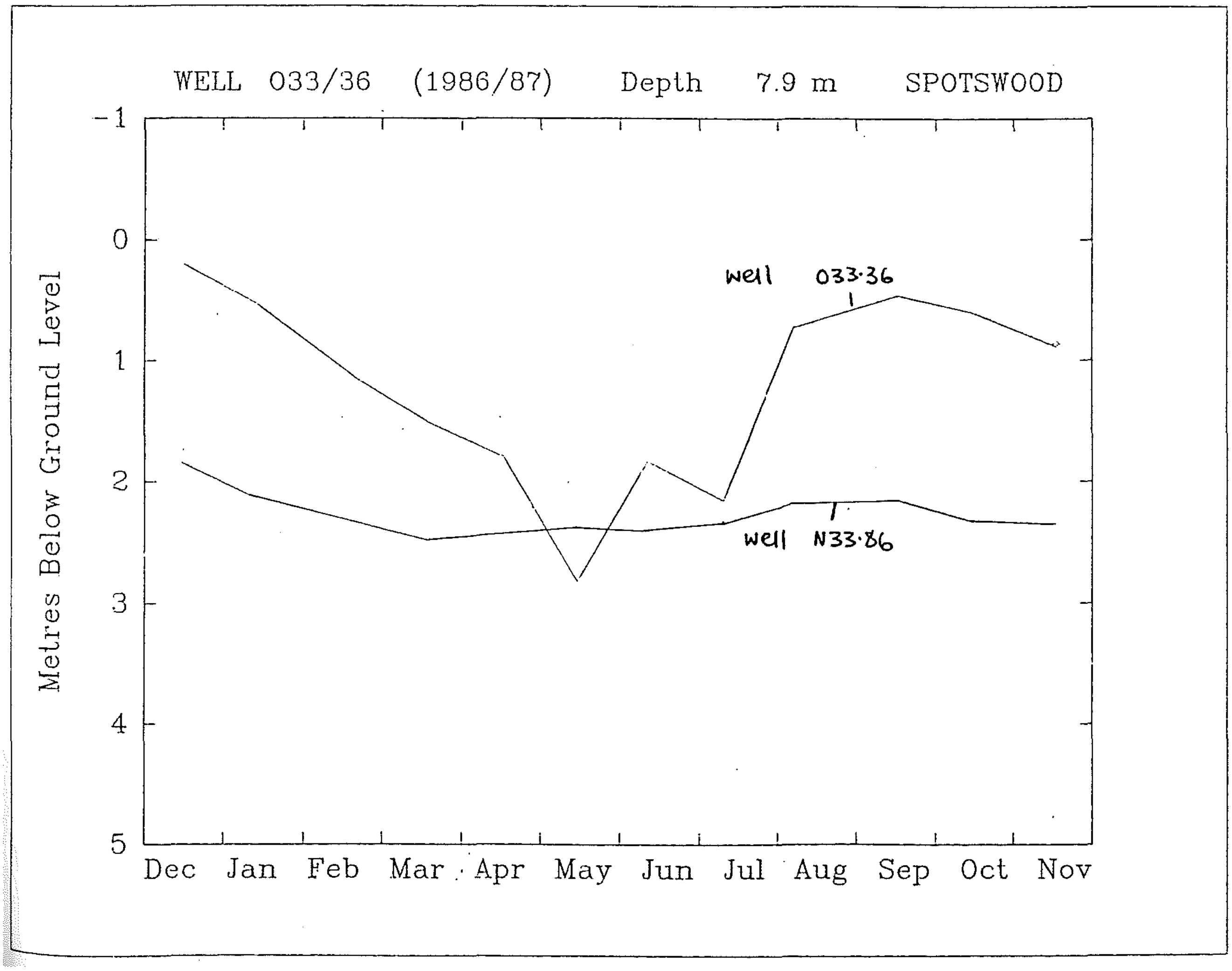



WELL N33/91 (1987) Depth 8.8 m CHEVIOT
Metres Below Ground Level
-1
1
3
5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
well O33·11
well O33·46
well N33·91

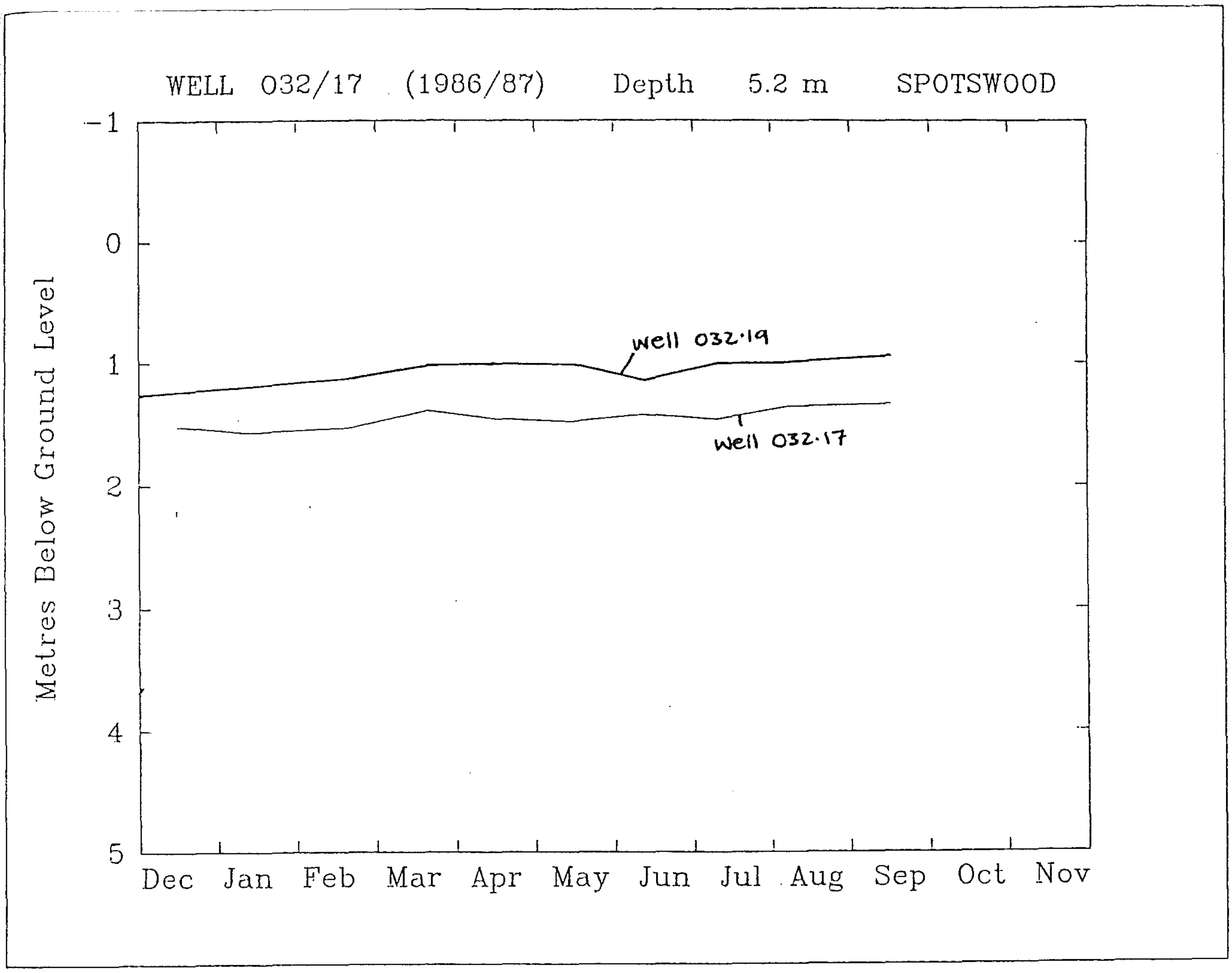

WELL O33/47 (1986/87) Depth 4.5 m CHEVIOT
Metres Below Ground Level
-1
1
3
5
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
well O33·47
well O33·26

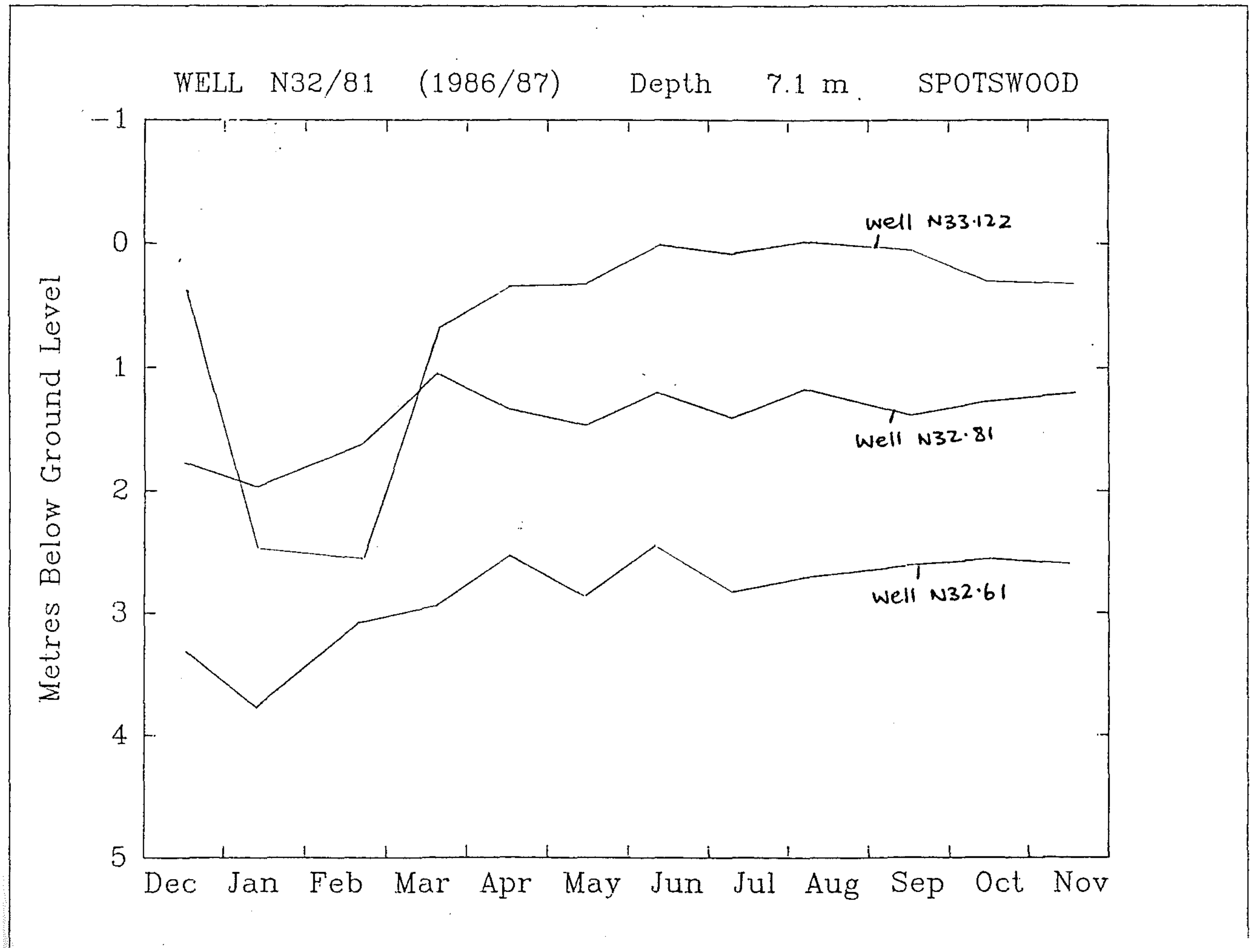


WELL N33/166 (1986/87) Depth 22.5 m SPOTSWOOD
Metres Below Ground Level
-1
0
1
2
3
4
5
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
Well N33·163
Well N33·166
DROPS TO 7·3m

WELL 033/36 (1986/87) Depth 7.9 m SPOTSWOOD
Metres Below Ground Level
-1
0
1
2
3
4
5
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
Well 033·36
Well N33·86


WELL 032/17 (1986/87) Depth 5.2 m SPOTSWOOD
Metres Below Ground Level
-1
0
1
2
3
4
5
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
well 032·19
well 032·17


WELL N32/81 (1986/87) Depth 7.1 m SPOTSWOOD
Metres Below Ground Level
-1
0
1
2
3
4
5
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
well N33·122
well N32·81
well N32·61

APPENDIX 4.6 - Data and drawdown curve obtained from constant discharge pump test 1 - bore N32.57. Spotswood.

OBSERVATIONS DURING PUMPING/RECOVERY

Location: Cheviot Water Supply, Learmington Rd, Spotswood
Well: N32/57 W. Daglish — Distance: Pumped Well, Drawdown
Start: 11·10 am — Stop: 15·10
Initial water level: 6·343 — Final water level: 
Reference level: = m above M.S.L.

| Time min. | Water Level m | Rise/ Fall | Time min. | Water Level m | Rise / Fall |
|---|---|---|---|---|---|
| 0 | 6·343 | 0·000 | 19 | 7·926 | 1·583 |
| ½ | 7·935 | 1·592 | 20 | 7·920 | 1·577 |
| 1 | 7·935 | 1·592 | 25 | 7·922 | 1·579 |
| 1½ | 7·932 | 1·589 | 30 | 7·918 | 1·575 |
| 2 | 7·939 | 1·596 | 35 | 7·923 | 1·580 |
| 2½ | 7·937 | 1·594 | 40 | 7·922 | 1·579 |
| 3 | 7·938 | 1·595 | 45 | 7·920 | 1·577 |
| 3½ | 7·934 | 1·591 | 50 | 7·924 | 1·581 |
| 4 | 7·932 | 1·589 | 55 | 7·915 | 1·572 |
| 4½ | 7·932 | 1·589 | 60 | 7·924 | 1·581 |
| 5 | 7·929 | 1·586 | 70 | 7·920 | 1·577 |
| 5½ | 7·926 | 1·583 | 80 | 7·925 | 1·582 |
| 6 | 7·930 | 1·587 | 90 | 7·925 | 1·582 |
| 6½ | 7·930 | 1·587 | 100 | 7·924 | 1·581 |
| 7 | 7·933 | 1·590 | 110 | 7·924 | 1·581 |
| 7½ | 7·930 | 1·587 | 120 | 7·912 | 1·569 |
| 8 | 7·931 | 1·588 | 150 | 7·920 | 1·578 |
| 8½ | 7·930 | 1·587 | 180 | 7·920 | 1·578 |
| 9 | 7·926 | 1·583 | 210 | 7·918 | 1·576 |
| 9½ | 7·925 | 1·582 | 237 | 7·752 | 1·409 |
| 10 | 7·929 | 1·586 | 240 | 7·685 | 1·342 |
| 11 | 7·921 | 1·578 | | | |
| 12 | 7·919 | 1·576 | | | |
| 13 | 7·917 | 1·574 | | | |
| 14 | 7·930 | 1·587 | | | |
| 15 | 7·920 | 1·577 | | | |
| 16 | 7·927 | 1·584 | | | |
| 17 | 7·924 | 1·581 | | | |
| 18 | 7·920 | 1·577 | | | |

Obs Well 1

OBSERVATIONS DURING PUMPING/RECOVERY

Location: Cheviot Water Supply, Learmington Rd, Spotswood
Well: N32/56 M. Lawler — Distance: 2·1 m
Start: — Stop: 
Initial water level: 6·331 m — Final water level: 
Reference level: = m above M.S.L.

| Time min. | Water Level m | Rise/ Fall | Time min. | Water Level m | Rise / Fall |
|---|---|---|---|---|---|
| 0 | 6·331 | 0·000 | 19 | 6·480 | 0·149 |
| ½ | 6·462 | 0·131 | 20 | 6·471 | 0·140 |
| 1 | 6·472 | 0·141 | 25 | 6·473 | 0·142 |
| 1½ | 6·480 | 0·149 | 30 | 6·476 | 0·145 |
| 2 | 6·482 | 0·151 | 35 | 6·479 | 0·148 |
| 2½ | 6·485 | 0·154 | 40 | 6·478 | 0·147 |
| 3 | 6·470 | 0·139 | 45 | 6·477 | 0·146 |
| 3½ | 6·468 | 0·137 | 50 | 6·474 | 0·143 |
| 4 | 6·470 | 0·139 | 55 | 6·475 | 0·144 |
| 4½ | 6·475 | 0·144 | 60 | 6·472 | 0·141 |
| 5 | 6·474 | 0·143 | 70 | 6·473 | 0·142 |
| 5½ | 6·474 | | 80 | 6·476 | 0·145 |
| 6 | 6·474 | | 90 | 6·478 | 0·147 |
| 6½ | 6·474 | | 100 | 6·480 | 0·149 |
| 7 | 6·474 | | 110 | 6·476 | 0·145 |
| 7½ | 6·469 | 0·138 | 120 | 6·474 | 0·143 |
| 8 | 6·470 | 0·139 | 150 | 6·476 | 0·145 |
| 8½ | 6·470 | | 180 | 6·475 | 0·144 |
| 9 | 6·471 | 0·140 | 210 | 6·474 | 0·143 |
| 9½ | 6·471 | | 240 | 6·474 | 0·143 |
| 10 | 6·471 | | | | |
| 11 | 6·479 | 0·148 | | | |
| 12 | 6·474 | 0·143 | | | |
| 13 | 6·476 | 0·145 | | | |
| 14 | 6·478 | 0·147 | | | |
| 15 | 6·470 | 0·139 | | | |
| 16 | 6·473 | 0·142 | | | |
| 17 | 6·470 | 0·139 | | | |
| 18 | 6·476 | 0·145 | | | |

Obs. well 2.

OBSERVATIONS DURING PUMPING/RECOVERY

Location Cheviot Water Supply, Leamington Rd, Spotswood

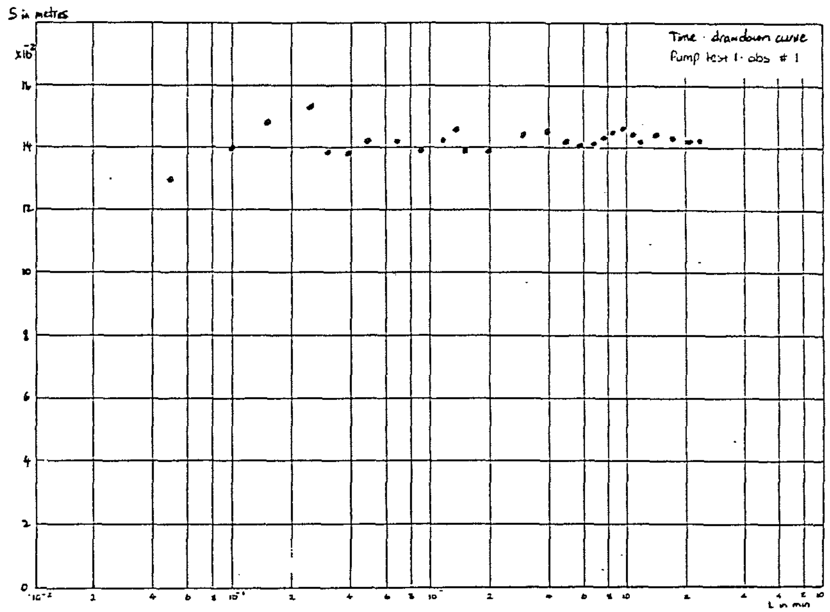
Well N32/104 P. Perkins Distance 27·4 m from pumped well

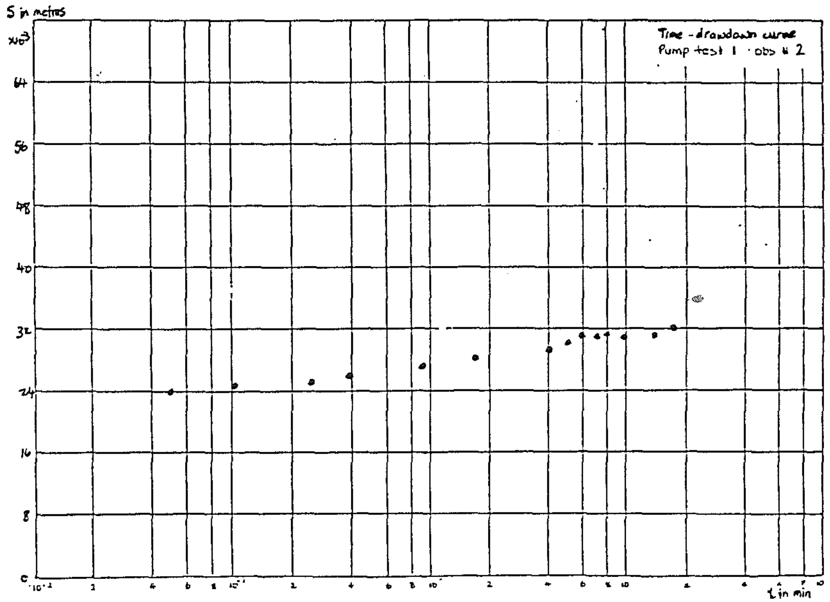
Start Stop

Initial water level 6·949 Final water level

Reference level = m above M.S.L.

| Time min. | Water Level m | Rise/ Fall | Time min. | Water Level m | Rise / Fall |
|---|---|---|---|---|---|
| 0 | 6·949 | 0·000 | 19 | 6·977 | 0·028 |
| ½ | 6·973 | 0·024 | 20 | 6·977 | |
| 1 | 6·973 | | 25 | 6·977 | |
| 1½ | 6·973 | | 30 | 6·977 | |
| 2 | 6·973 | | 35 | 6·977 | |
| 2½ | 6·974 | 0·025 | 40 | 6·978 | 0·029 |
| 3 | 6·974 | | 45 | 6·979 | 0·030 |
| 3½ | 6·974 | | 50 | 6·979 | |
| 4 | 6·975 | 0·026 | 55 | 6·980 | 0·031 |
| 4½ | 6·975 | | 60 | 6·980 | 0·031 |
| 5 | 6·975 | | 70 | 6·981 | 0·032 |
| 5½ | 6·975 | | 80 | 6·982 | 0·033 |
| 6 | 6·975 | | 90 | 6·980 | 0·031 |
| 6½ | 6·975 | | 100 | 6·981 | 0·032 |
| 7 | 6·975 | | 110 | 6·982 | 0·033 |
| 7½ | 6·975 | | 120 | 6·983 | 0·034 |
| 8 | 6·975 | | 150 | 6·982 | 0·033 |
| 8½ | 6·975 | | 180 | 6·981 | 0·032 |
| 9 | 6·976 | 0·027 | 230 | 6·985 | 0·036 |
| 9½ | 6·976 | | | | |
| 10 | 6·976 | | | | |
| 11 | 6·976 | | | | |
| 12 | 6·976 | | | | |
| 13 | 6·976 | | | | |
| 14 | 6·976 | | | | |
| 15 | 6·976 | | | | |
| 16 | 6·976 | | | | |
| 17 | 6·977 | 0·028 | | | |
| 18 | 6·977 | | | | |



APPENDIX 4.7 - Data and drawdown curve obtained from constant discharge pump test 2- bore 032.19, Spotswood.

OBSERVATIONS DURING PUMPING/RECOVERY

Location T. Barnes, Spotswood

Well 032/19 N Baglish  Distance Pumped Well  Drawdown

Start 10.27 19.8.57  Stop

Initial water level 1.104 m  Final water level

Reference level = m above M.S.L.

| Time min. | Water Level m | Rise/ Fall | Time min. | Water Level m | Rise/ Fall |
|---|---|---|---|---|---|
| 0 | 1.104 | 0.000 | 60 | 5.596 | 4.492 |
| ½ | 4.300 | 3.196 | 70 | 5.595 | 4.491 |
| 1 | | | 80 | 5.595 | 4.491 |
| 1½ | 4.704 | 3.600 | 90 | 5.611 | 4.507 |
| 2 | 5.250 | 4.146 | 100 | 5.605 | 4.501 |
| 2½ | 5.300 | 4.196 | 120 | 5.616 | 4.512 |
| 3 | 5.368 | 4.264 | 150 | 5.612 | 4.508 |
| 3½ | 5.396 | 4.292 | 180 | 5.635 | 4.531 |
| 4 | 5.453 | 4.349 | 210 | 5.642 | 4.538 |
| 4½ | 5.470 | 4.366 | 240 | 5.657 | 4.553 |
| 5 | 5.485 | 4.381 | | | |
| 5½ | 5.500 | 4.396 | | | |
| 6 | 5.496 | 4.392 | | | |
| 7 | 5.496 | 4.392 | | | |
| 8 | 5.525 | 4.421 | | | |
| 9 | 5.535 | 4.431 | | | |
| 10 | 5.535 | 4.431 | | | |
| 12 | 5.535 | 4.431 | | | |
| 14 | 5.525 | 4.421 | | | |
| 17 | 5.555 | 4.451 | | | |
| 18 | 5.550 | 4.446 | | | |
| 20 | 5.548 | 4.444 | | | |
| 25 | 5.556 | 4.452 | | | |
| 30 | 5.568 | 4.464 | | | |
| 35 | 5.565 | 4.461 | | | |
| 40 | 5.574 | 4.470 | | | |
| 45 | 5.580 | 4.476 | | | |
| 50 | 5.561 | 4.457 | | | |
| 55 | 5.596 | 4.492 | | | |

OBSERVATIONS DURING PUMPING/RECOVERY

Location T Barnes

Well Obs. Well 1 J. Purdie  Distance 9.85 m from pumped bore.

Start 10.27 19.8.57  Stop Obs 1 Drawdown.

Initial water level 2.000  Final water level

Reference level = m above M.S.L.

| Time min. | Water Level m | Rise/ Fall | Time min. | Water Level m | Rise/ Fall |
|---|---|---|---|---|---|
| 0 | 2.000 | 0.000 | 60 | 3.305 | 1.305 |
| ½ | 3.003 | 1.003 | 70 | 3.310 | 1.310 |
| 1 | 3.064 | 1.064 | 80 | 3.311 | 1.311 |
| 1½ | 3.030 | 1.030 | 90 | 3.302 | 1.302 |
| 2 | | | 100 | 3.309 | 1.309 |
| 2½ | 3.161 | 1.161 | 110 | 3.309 | 1.309 |
| 3 | 3.200 | 1.200 | 120 | 3.310 | 1.310 |
| 3½ | 3.215 | 1.215 | 150 | 3.310 | 1.310 |
| 4 | 3.232 | 1.232 | 180 | 3.313 | 1.313 |
| 4½ | 3.246 | 1.246 | 210 | 3.313 | 1.313 |
| 5 | 3.252 | 1.252 | 240 | 3.311 | 1.311 |
| 5½ | 3.259 | 1.259 | 270 | 3.314 | 1.314 |
| 6 | 3.262 | 1.262 | 300 | 3.314 | 1.314 |
| 7 | 3.267 | 1.267 | | | |
| 8 | 3.275 | 1.275 | | | |
| 9 | 3.277 | 1.277 | | | |
| 10 | 3.279 | 1.279 | | | |
| 12 | 3.280 | 1.280 | | | |
| 14 | 3.287 | 1.287 | | | |
| 16 | 3.285 | 1.285 | | | |
| 18 | 3.289 | 1.289 | | | |
| 20 | 3.290 | 1.290 | | | |
| 25 | 3.294 | 1.294 | | | |
| 30 | 3.305 | 1.305 | | | |
| 35 | 3.303 | 1.303 | | | |
| 40 | 3.301 | 1.301 | | | |
| 45 | 3.300 | 1.300 | | | |
| 50 | 3.298 | 1.298 | | | |
| 55 | 3.307 | 1.307 | | | |

OBSERVATIONS DURING PUMPING/RECOVERY

Location T Barnes

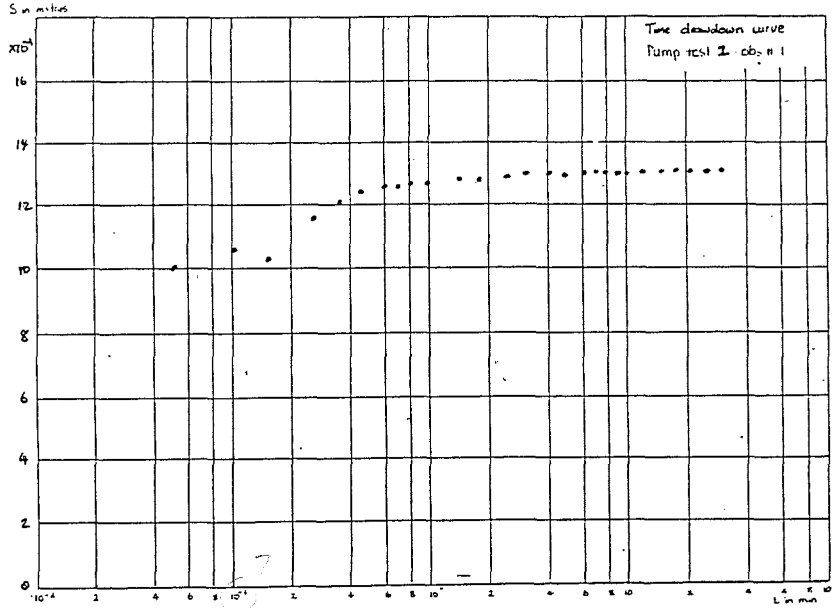
Well Obs 2 Simon Leech Distance 24.7m from pumped bore

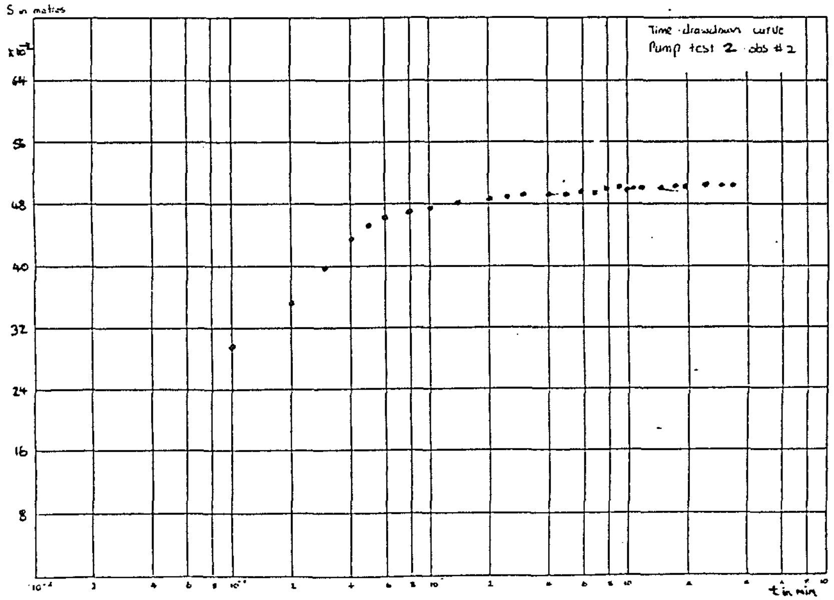
Start Stop Obs well 2 , Drawdown

Initial water level 1.735 Final water level

Reference level = m above M.S.L.

| Time min. | Water Level m | Rise/ Fall | Time min. | Water Level m | Rise / Fall |
|---|---|---|---|---|---|
| 0 | 1.735 | 0.000 | 60 | 2.237 | 0.502 |
| ½ | | | 70 | 2.234 | 0.499 |
| 1 | 2.033 | 0.298 | 80 | 2.239 | 0.503 |
| 1½ | - | | 90 | 2.240 | 0.505 |
| 2 | 2.091 | 0.356 | 100 | 2.237 | 0.502 |
| 2½ | | | 110 | 2.240 | 0.505 |
| 3 | 2.143 | 0.408 | 120 | 2.240 | 0.505 |
| 3½ | | | 150 | 2.239 | 0.504 |
| 4 | 2.172 | 0.437 | 180 | 2.241 | 0.506 |
| 4½ | | | 210 | 2.241 | 0.506 |
| 5 | 2.187 | 0.452 | 240 | 2.241 | 0.506 |
| 5½ | | | 270 | 2.243 | 0.508 |
| 6 | 2.196 | 0.461 | 300 | 2.244 | 0.509 |
| 7 | 2.202 | 0.467 | | | |
| 8 | 2.207 | 0.472 | | | |
| 9 | 2.210 | 0.475 | | | |
| 10 | 2.214 | 0.479 | | | |
| 12 | 2.216 | 0.481 | | | |
| 14 | 2.219 | 0.484 | | | |
| 16 | 2.220 | 0.485 | | | |
| 18 | 2.222 | 0.487 | | | |
| 20 | 2.224 | 0.489 | | | |
| 25 | 2.228 | 0.493 | | | |
| 30 | 2.231 | 0.496 | | | |
| 35 | 2.232 | 0.497 | | | |
| 40 | 2.231 | 0.496 | | | |
| 45 | 2.233 | 0.498 | | | |
| 50 | 2.232 | 0.496 | | | |
| 55 | 2.229 | 0.494 | | | |



APPENDIX 4·8 - Data and drawdown curve obtained from step drawdown test carried out on bore N32·19, Spotswood

Pumped Well
Step Test

OBSERVATIONS DURING PUMPING/RECOVERY

Location T. Barnes Spotswood

Well N32/19 Distance

Start 10·02 hrs 20/8/87 Stop

Initial water level 1·115 Final water level

Reference level = m above M.S.L.

Step 1 → (time 0); Q = 0·420 m³/min

← Step 2 (time 55); Q = 0·498 m³/min

| Time min. | Water Level m | Rise/ Fall | Time min. | Water Level m | Rise/ Fall |
|---|---|---|---|---|---|
| 0 | 1·115 | 0·000 | 55 | 2·838 | 1·723 |
| ½ | 2·802 | 1·687 | 55½ | 3·216 | 2·101 |
| 1 | 2·802 | 1·687 | 56 | 3·233 | 2·118 |
| 1½ | 2·803 | 1·688 | 56½ | 3 243 | 2·128 |
| 2 | 2·810 | 1·695 | 57 | 3·245 | 2·130 |
| 2½ | 2·810 | 1·695 | 57½ | 3·249 | 2·134 |
| 3 | 2·812 | 1·697 | 58 | 3·248 | 2·133 |
| 3½ | 2·816 | 1·701 | 58½ | 3·251 | 2·136 |
| 4 | 2·819 | 1·704 | 59 | 3·253 | 2·138 |
| 4½ | | | 59½ | 3·256 | 2·141 |
| 5 | 2·821 | 1·706 | 60 | 3·254 | 2·139 |
| 6 | 2·822 | 1·707 | 61 | 3·255 | 2·140 |
| 7 | 2·822 | 1·707 | 62 | 3·258 | 2·143 |
| 8 | 2·825 | 1·710 | 63 | 3·260 | 2·145 |
| 9 | 2827 | 1·712 | 64 | 3·260 | 2·145 |
| 10 | 2·823 | 1·708 | 5 | 3·260 | 2·145 |
| 12 | 2·821 | 1·706 | 67 | 3·261 | 2·146 |
| 14 | 2·820 | 1·705 | 69 | 3·260 | 2·145 |
| 16 | 2·822 | 1·707 | 71 | 3·260 | 2·145 |
| 18 | 2·818 | 1·703 | 73 | 3·260 | 2·14 |
| 20 | 2·817 | 1·702 | 75 | 3·259 | 2·16 |
| 25 | 2·835 | 1·720 | 80 | 3·276 | 2·161 |
| 30 | 2·830 | 1·715 | 85 | 3·275 | 2·160 |
| 35 | 2·832 | 1·717 | 90 | 3·275 | 2·160 |
| 40 | 2·830 | 1·715 | 95 | 3·275 | 2·160 |
| 45 | 2·831 | 1·716 | 100 | 3·276 | 2·161 |
| 50 | 2·833 | 1·718 | 105 | 3·276 | 2·161 |
| 55 | 2·838 | 1·723 | 110 | 3·276 | 2·161 |
| | | | | | |

OBSERVATIONS DURING PUMPING/RECOVERY

Location

Well Distance

Start Stop

Initial water level Final water level

Reference level = m above M.S.L.

Step 3 → (time 110); Q = 0·618 m³/min

← Step 4 (time 165); Q = 0·723 m³/min

| Time min. | Water Level m | Rise/ Fall | Time min. | Water Level m | Rise/ Fall |
|---|---|---|---|---|---|
| 110 | 3·276 | 2·161 | 165 | 4·100 | 2·985 |
| 110½ | 3·820 | 2·705 | 165½ | | |
| 111 | 3·975 | 2·860 | 166 | 4·889 | 3·774 |
| 111½ | 4·010 | 2·895 | 166½ | 4·914 | 3·799 |
| 112 | 4·025 | 2·910 | 167 | 4·926 | 3·811 |
| 112½ | 4·031 | 2·916 | 167½ | 4·931 | 3·816 |
| 113 | 4·037 | 2·922 | 168 | 4·936 | 3·821 |
| 113½ | 4·036 | 2·921 | 168½ | 4·944 | 3·829 |
| 114 | | | 169 | 4·967 | 3·852 |
| 114½ | 4·050 | 2·935 | 169½ | 4·970 | 3·855 |
| 115 | 4·053 | 2·928 | 170 | 4·970 | 3·855 |
| 116 | 4·060 | 2·945 | 171 | 4·984 | 3·869 |
| 117 | 4·060 | 2·945 | 172 | 4·983 | 3·868 |
| 118 | 4·061 | 2·946 | 173 | 4·990 | 2·875 |
| 119 | 4·064 | 2·949 | 174 | 4·991 | 3 876 |
| 120 | 4·067 | 2·952 | 175 | 4·995 | 3·880 |
| 122 | 4·069 | 2·954 | 177 | 5·000 | 3·885 |
| 124 | 4·068 | 2·953 | 179 | 5·000 | 3·885 |
| 126 | 4·075 | 2·960 | 181 | 5·003 | 3 888 |
| 128 | 4·076 | 2·961 | 183 | 5·006 | 3·891 |
| 130 | 4·077 | 2·962 | 185 | 5·010 | 3·895 |
| 135 | 4·085 | 2·970 | 190 | 5·012 | 3·897 |
| 140 | 4·085 | 2·970 | 195 | 5·012 | 3·897 |
| 145 | 4·087 | 2·972 | 200 | 5·013 | 3·898 |
| 150 | 4·089 | 2·974 | 205 | 5·015 | 3·900 |
| 155 | 4·091 | 2·976 | 213 | 5·020 | 3·905 |
| 160 | 4·095 | 2·980 | 217 | 5·024 | 3·909 |
| 165 | 4·074 | 2·979 | 220 | 5·026 | 3·911 |
| | | | | | |

APPENDIX

## METHOD OF ANALYSIS

### JACOB (1946)

| STEP | ΔSw (M) | ΔQ ($m^3$/min) | ΔSw / ΔQ | C |
|---|---|---|---|---|
| 1 | 1.716 | 0.42 | 4.08 | ~~2.87~~ |
| 2 | 0.43 | 0.078 | 5.51 | 2.87 |
| 3 | 0.83 | 0.12 | 6.92 | 7.12 |
| 4 | 0.92 | 0.105 | 8.76 | 8.18 |

WHERE $C = \dfrac{\Delta Sw^{i} / \Delta Q^{i} - \Delta Sw^{i-1} / \Delta Q^{i-1}}{\Delta Q^{i-1} + \Delta Q^{i}}$

FOR STEP

2 $\quad C = \dfrac{5.51 - 4.08}{0.078 + 0.42} = \dfrac{1.43}{0.498} = 2.87$

3 $\quad C = \dfrac{6.92 - 5.51}{0.12 + 0.078} = \dfrac{1.41}{0.198} = 7.12$

4 $\quad C = \dfrac{8.76 - 6.92}{0.105 + 0.12} = \dfrac{1.84}{0.225} = 8.18$

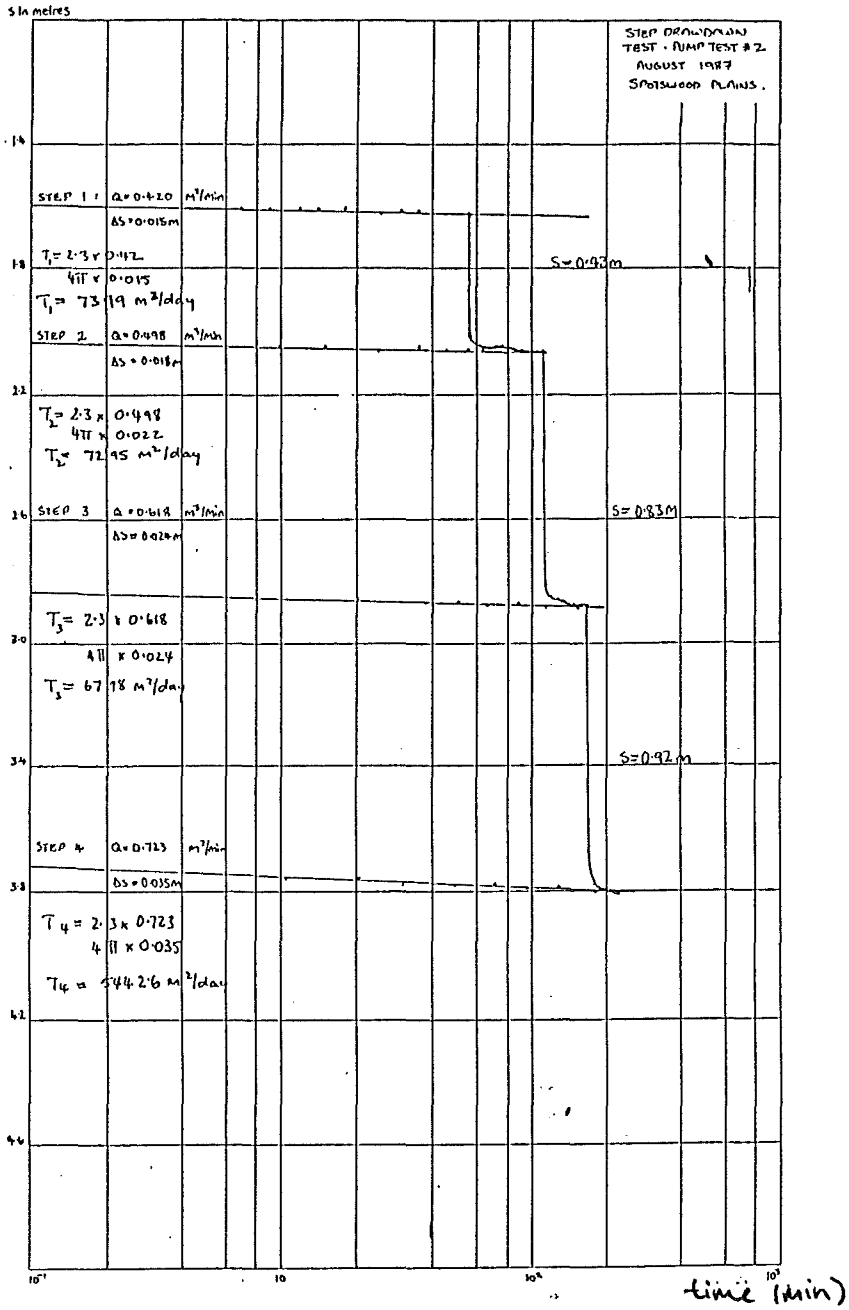
## METHOD OF ANALYSIS

### BIERSCHENK AND WILSON

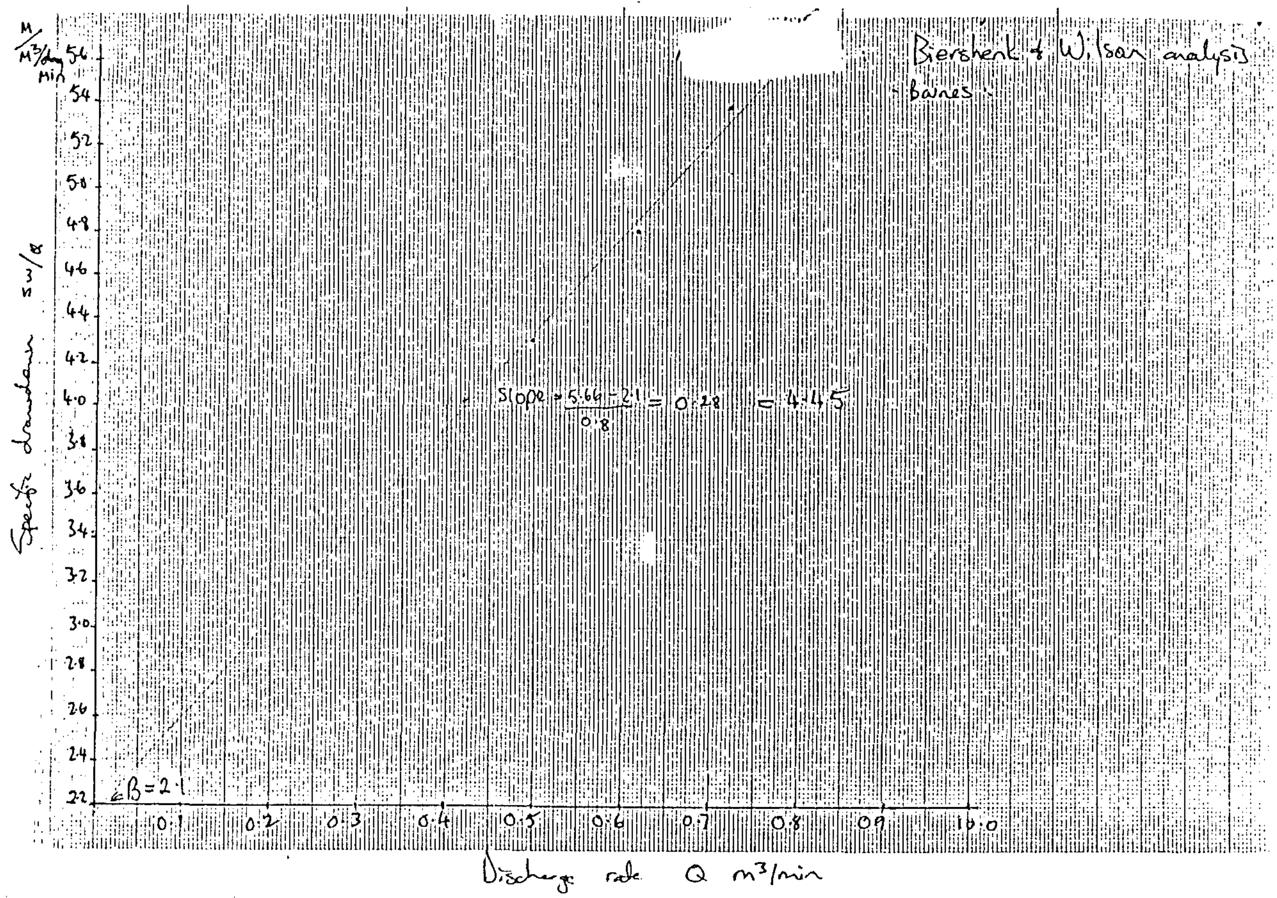
| STEP | Total Sw (m) | Total Q ($M^3$/Min) | Swtotal / Qtotal |
|---|---|---|---|
| 1 | 1.716 | 0.42 | 4.08 |
| 2 | 2.146 | 0.498 | 4.309 |
| 3 | 2.976 | 0.618 | 4.816 |
| 4 | 3.896 | 0.723 | 5.389 |

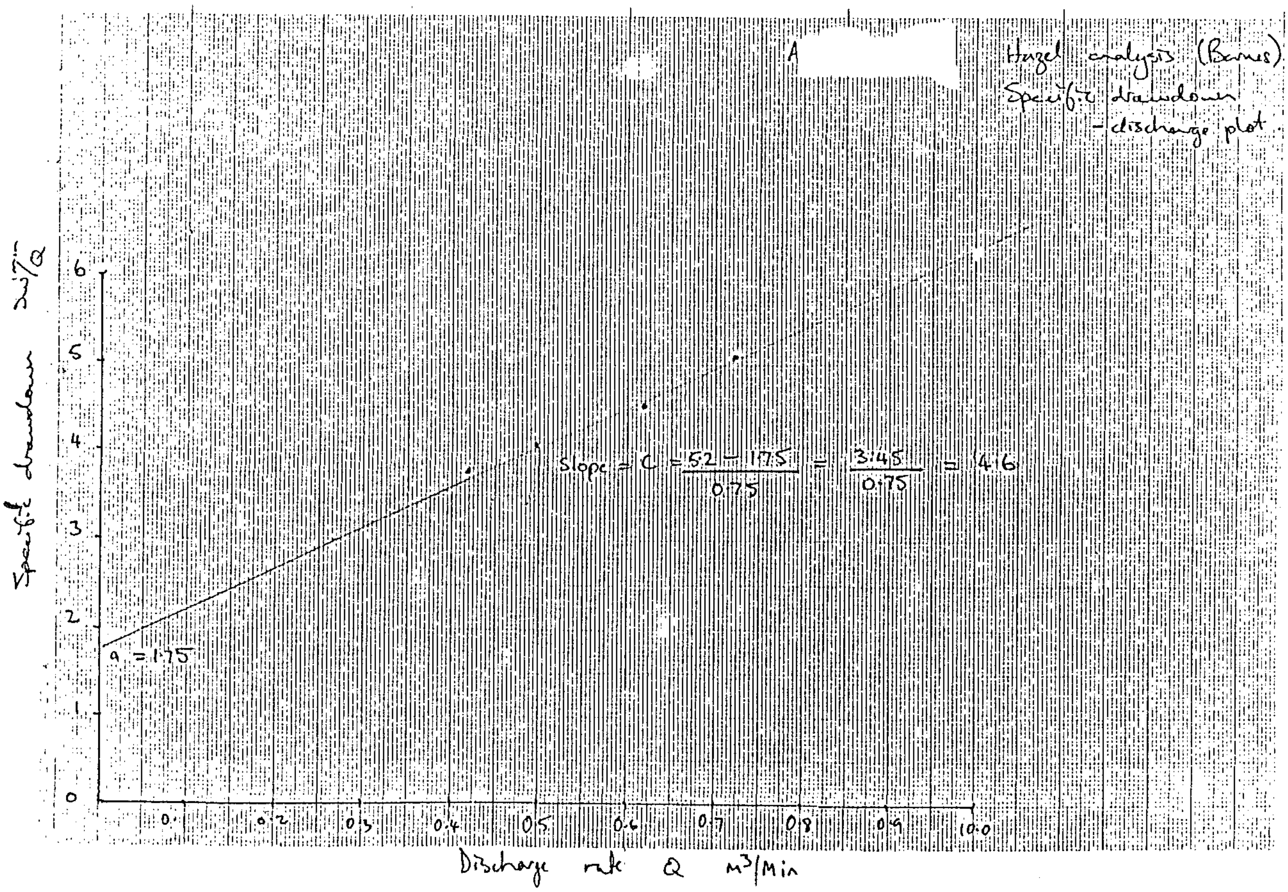
### HAZEL

| STEP | ΔSw (M) | Q ($m^3$/min) | ΔSw/Q $\times 10^{-1}$ | Sw/min | $Sw^{1min}/Q$ |
|---|---|---|---|---|---|
| 1 | 0.015 | 0.42 | 0.357 | 1.6 | 3.81 |
| 2 | 0.018 | 0.498 | 0.361 | 2.02 | 4.06 |
| 3 | 0.024 | 0.618 | 0.388 | 2.83 | 4.58 |
| 4 | 0.035 | 0.723 | 0.484 | 3.71 | 5.13 |




| STEP | $\Delta s_w$ (m) | Q ($m^3$/min) | $\Delta s_w/Q$ $\times 10^{-1}$ | $s_w$; 1 min | $s_w^{1\,min}/Q$ |
|---|---|---|---|---|---|
| 1 | 0.015 | 0.42 | 0.357 | 1.6 | 3.81 |
| 2 | 0.018 | 0.498 | 0.361 | 2.02 | 4.06 |
| 3 | 0.024 | 0.618 | 0.388 | 2.83 | 4.58 |
| 4 | 0.035 | 0.723 | 0.484 | 3.71 | 5.13 |


Biershenk & Wilson analysis
- barnes -
Specific drawdown sw/Q
M/M³/day min
Slope = 5.66 - 2.1 / 0.8 = 0.28 = 4.45
B = 2.1
Discharge rate Q m³/min


Hazel analysis (Barnes)
Specific drawdown
- discharge plot
Specific drawdown sw/Q
Slope = C = 5.2 - 1.75 / 0.75 = 3.45 / 0.75 = 4.6
a = 1.75
Discharge rate Q m³/Min

STEP DRAWDOWN TEST – W32-19 ...

STEP DRAWDOWN PROGRAM (VAX VERSION)

TABLE OF VALUES

| Time | Discharge | H | Computed Drawdown | Actual Drawdown | Difference in Drawdown | Recorded Head | 24 Hr O/S | Well Loss |
|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.115 | 0.000 | 0.000 |
| 0.50 | 0.420 | -0.126 | 1.681 | 1.687 | -0.006 | 2.802 | 0.244 | 1.085 |
| 1.00 | 0.420 | 0.000 | 1.695 | 1.697 | -0.002 | 2.812 | 0.244 | 1.085 |
| 1.50 | 0.420 | 0.074 | 1.687 | 1.688 | -0.001 | 2.803 | 0.244 | 1.085 |
| 2.00 | 0.420 | 0.126 | 1.689 | 1.695 | -0.006 | 2.810 | 0.244 | 1.085 |
| 3.00 | 0.420 | 0.200 | 1.691 | 1.697 | -0.006 | 2.812 | 0.244 | 1.085 |
| 4.00 | 0.420 | 0.233 | 1.693 | 1.704 | -0.011 | 2.819 | 0.244 | 1.085 |
| 5.00 | 0.420 | 0.254 | 1.694 | 1.706 | -0.012 | 2.821 | 0.244 | 1.085 |
| 6.00 | 0.420 | 0.327 | 1.695 | 1.707 | -0.012 | 2.822 | 0.244 | 1.085 |
| 7.00 | 0.420 | 0.355 | 1.696 | 1.707 | -0.011 | 2.822 | 0.244 | 1.085 |
| 8.00 | 0.420 | 0.379 | 1.696 | 1.710 | -0.014 | 2.825 | 0.244 | 1.085 |
| 9.00 | 0.420 | 0.401 | 1.697 | 1.712 | -0.015 | 2.827 | 0.244 | 1.085 |
| 10.00 | 0.420 | 0.420 | 1.698 | 1.708 | -0.010 | 2.823 | 0.244 | 1.085 |
| 12.00 | 0.420 | 0.452 | 1.699 | 1.706 | -0.007 | 2.821 | 0.244 | 1.085 |
| 14.00 | 0.420 | 0.481 | 1.700 | 1.705 | -0.005 | 2.820 | 0.244 | 1.085 |
| 16.00 | 0.420 | 0.506 | 1.700 | 1.707 | -0.007 | 2.822 | 0.244 | 1.085 |
| 18.00 | 0.420 | 0.527 | 1.701 | 1.703 | -0.002 | 2.818 | 0.244 | 1.085 |
| 20.00 | 0.420 | 0.546 | 1.701 | 1.702 | -0.001 | 2.817 | 0.244 | 1.085 |
| 25.00 | 0.420 | 0.587 | 1.703 | 1.720 | -0.017 | 2.835 | 0.244 | 1.085 |
| 30.00 | 0.420 | 0.620 | 1.704 | 1.715 | -0.011 | 2.830 | 0.244 | 1.085 |
| 35.00 | 0.420 | 0.647 | 1.704 | 1.717 | -0.013 | 2.832 | 0.244 | 1.085 |
| 40.00 | 0.420 | 0.673 | 1.705 | 1.715 | -0.010 | 2.830 | 0.244 | 1.085 |
| 45.00 | 0.420 | 0.694 | 1.706 | 1.716 | -0.010 | 2.831 | 0.244 | 1.085 |
| 50.00 | 0.420 | 0.714 | 1.706 | 1.718 | -0.012 | 2.833 | 0.244 | 1.085 |
| 55.00 | 0.420 | 0.731 | 1.707 | 1.716 | -0.009 | 2.831 | 0.244 | 1.085 |
| 56.50 | 0.500 | 0.750 | 2.155 | 2.128 | 0.027 | 3.243 | 0.229 | 1.538 |
| 57.00 | 0.500 | 0.762 | 2.155 | 2.130 | 0.025 | 3.245 | 0.229 | 1.538 |
| 57.50 | 0.500 | 0.771 | 2.155 | 2.134 | 0.021 | 3.249 | 0.229 | 1.538 |
| 58.00 | 0.500 | 0.779 | 2.156 | 2.133 | 0.023 | 3.248 | 0.229 | 1.538 |
| 59.00 | 0.500 | 0.792 | 2.156 | 2.138 | 0.018 | 3.253 | 0.229 | 1.538 |
| 60.00 | 0.500 | 0.803 | 2.156 | 2.139 | 0.017 | 3.254 | 0.229 | 1.538 |
| 61.00 | 0.500 | 0.812 | 2.157 | 2.140 | 0.017 | 3.255 | 0.229 | 1.538 |
| 62.00 | 0.500 | 0.820 | 2.157 | 2.143 | 0.014 | 3.258 | 0.229 | 1.538 |
| 63.00 | 0.500 | 0.828 | 2.157 | 2.145 | 0.012 | 3.260 | 0.229 | 1.538 |
| 64.00 | 0.500 | 0.835 | 2.157 | [illegible] | 0.012 | 3.260 | 0.229 | 1.538 |
| 65.00 | 0.500 | 0.841 | 2.158 | 2.145 | 0.013 | 3.260 | 0.229 | 1.538 |
| 67.00 | 0.500 | 0.853 | 2.158 | 2.146 | 0.012 | 3.261 | 0.229 | 1.538 |
| 69.00 | 0.500 | 0.864 | 2.158 | 2.145 | 0.013 | 3.260 | 0.229 | 1.538 |
| 71.00 | 0.500 | 0.874 | 2.159 | 2.145 | 0.014 | 3.260 | 0.229 | 1.538 |
| 73.00 | 0.500 | 0.883 | 2.159 | 2.145 | 0.014 | 3.260 | 0.229 | 1.538 |
| 75.00 | 0.500 | 0.892 | 2.159 | 2.144 | 0.015 | 3.259 | 0.229 | 1.538 |
| 80.00 | 0.500 | 0.911 | 2.160 | 2.161 | -0.001 | 3.276 | 0.229 | 1.538 |
| 85.00 | 0.500 | 0.929 | 2.160 | 2.160 | 0.000 | 3.275 | 0.229 | 1.538 |
| 90.00 | 0.500 | 0.944 | 2.161 | 2.160 | 0.001 | 3.275 | 0.229 | 1.538 |
| 95.00 | 0.500 | 0.957 | 2.161 | 2.160 | 0.001 | 3.275 | 0.229 | 1.538 |
| 100.00 | 0.500 | 0.972 | 2.162 | 2.161 | 0.001 | 3.276 | 0.229 | 1.538 |
| 105.00 | 0.500 | 0.985 | 2.162 | 2.161 | 0.001 | 3.276 | 0.229 | 1.538 |
| 110.00 | 0.500 | 0.997 | 2.162 | 2.161 | 0.001 | 3.276 | 0.229 | 1.538 |
| 113.00 | 0.618 | 1.060 | 2.968 | 2.922 | 0.046 | 4.037 | 0.206 | 2.349 |
| 114.00 | 0.618 | 1.077 | 2.968 | 2.928 | 0.040 | 4.043 | 0.206 | 2.349 |
| 115.00 | 0.619 | 1.090 | 2.969 | 2.938 | 0.031 | 4.053 | 0.206 | 2.349 |
| 116.00 | 0.618 | 1.102 | 2.969 | 2.945 | 0.024 | 4.060 | 0.206 | 2.349 |
| 117.00 | 0.618 | 1.112 | 2.969 | 2.945 | 0.024 | 4.060 | 0.206 | 2.349 |
| 118.00 | 0.618 | 1.121 | 2.969 | 2.946 | 0.023 | 4.061 | 0.206 | 2.349 |
| 119.00 | 0.618 | 1.129 | 2.970 | 2.949 | 0.021 | 4.064 | 0.206 | 2.349 |
| 120.00 | 0.618 | 1.136 | 2.970 | 2.952 | 0.018 | 4.067 | 0.206 | 2.349 |
| 122.00 | 0.618 | 1.150 | 2.970 | 2.954 | 0.016 | 4.069 | 0.206 | 2.349 |
| 124.00 | 0.618 | 1.162 | 2.971 | 2.953 | 0.018 | 4.068 | 0.206 | 2.349 |
| 126.00 | 0.618 | 1.172 | 2.971 | 2.960 | 0.011 | 4.075 | 0.206 | 2.349 |
| 128.00 | 0.618 | 1.182 | 2.971 | 2.961 | 0.010 | 4.076 | 0.206 | 2.349 |
| 130.00 | 0.618 | 1.191 | 2.972 | 2.962 | 0.010 | 4.077 | 0.206 | 2.349 |
| 135.00 | 0.618 | 1.212 | 2.972 | 2.970 | 0.002 | 4.085 | 0.206 | 2.349 |
| 140.00 | 0.618 | 1.230 | 2.973 | 2.970 | 0.003 | 4.085 | 0.206 | 2.349 |
| 145.00 | 0.618 | 1.246 | 2.973 | 2.972 | 0.001 | 4.087 | 0.206 | 2.349 |
| 150.00 | 0.618 | 1.261 | 2.974 | 2.974 | 0.000 | 4.089 | 0.206 | 2.349 |
| 155.00 | 0.618 | 1.275 | 2.974 | 2.976 | -0.002 | 4.091 | 0.206 | 2.349 |
| 160.00 | 0.618 | 1.289 | 2.974 | 2.980 | -0.006 | 4.095 | 0.206 | 2.349 |
| 165.00 | 0.618 | 1.300 | 2.975 | 2.979 | -0.004 | 4.094 | 0.206 | 2.349 |
| 170.00 | 0.723 | 1.385 | 3.836 | 3.855 | -0.019 | 4.970 | 0.187 | 3.215 |
| 171.00 | 0.723 | 1.395 | 3.837 | 3.869 | -0.032 | 4.984 | 0.187 | 3.215 |
| 172.00 | 0.723 | 1.405 | 3.837 | 3.868 | -0.031 | 4.983 | 0.187 | 3.215 |
| 173.00 | 0.723 | 1.413 | 3.837 | 3.875 | -0.038 | 4.990 | 0.187 | 3.215 |
| 174.00 | 0.723 | 1.420 | 3.837 | 3.876 | -0.039 | 4.991 | 0.187 | 3.215 |
| 175.00 | 0.723 | 1.427 | 3.838 | 3.880 | -0.042 | 4.995 | 0.187 | 3.215 |
| 177.00 | 0.723 | 1.440 | 3.838 | 3.885 | -0.047 | 5.000 | 0.187 | 3.215 |
| 179.00 | 0.723 | 1.451 | 3.838 | 3.885 | -0.047 | 5.000 | 0.187 | 3.215 |
| 181.00 | 0.723 | 1.461 | 3.839 | 3.888 | -0.049 | 5.003 | 0.187 | 3.215 |
| 183.00 | 0.723 | 1.470 | 3.839 | 3.891 | -0.052 | 5.006 | 0.187 | 3.215 |
| 185.00 | 0.723 | 1.479 | 3.839 | 3.895 | -0.056 | 5.010 | 0.187 | 3.215 |
| 190.00 | 0.723 | 1.499 | 3.840 | 3.897 | -0.057 | 5.012 | 0.187 | 3.215 |
| 195.00 | 0.723 | 1.516 | 3.840 | 3.897 | -0.057 | 5.012 | 0.187 | 3.215 |
| 200.00 | 0.723 | 1.530 | 3.841 | 3.898 | -0.057 | 5.013 | 0.187 | 3.215 |
| 205.00 | 0.723 | 1.547 | 3.841 | 3.900 | -0.059 | 5.015 | 0.187 | 3.215 |
| 210.00 | 0.723 | 1.568 | 3.842 | 3.905 | -0.063 | 5.020 | 0.187 | 3.215 |
| 215.00 | 0.723 | 1.578 | 3.842 | 3.909 | -0.067 | 5.024 | 0.187 | 3.215 |
| 220.00 | 0.723 | 1.585 | 3.842 | 3.911 | -0.069 | 5.026 | 0.187 | 3.215 |
| 223.50 | 0.780 | 1.624 | 4.367 | 4.312 | 0.055 | 5.427 | 0.178 | 3.742 |
| 224.00 | 0.780 | 1.628 | 4.367 | 4.310 | 0.057 | 5.425 | 0.178 | 3.742 |
| 225.00 | 0.780 | 1.636 | 4.367 | 4.324 | 0.043 | 5.439 | 0.178 | 3.742 |
| 226.00 | 0.780 | 1.643 | 4.367 | 4.325 | 0.042 | 5.440 | 0.178 | 3.742 |
| 227.00 | 0.780 | 1.649 | 4.367 | 4.323 | 0.044 | 5.438 | 0.178 | 3.742 |
| 228.00 | 0.780 | 1.654 | 4.368 | 4.326 | 0.042 | 5.441 | 0.178 | 3.742 |
| 229.00 | 0.780 | 1.659 | 4.368 | 4.326 | 0.042 | 5.441 | 0.178 | 3.742 |
| 230.00 | 0.780 | 1.664 | 4.368 | 4.328 | 0.040 | 5.443 | 0.178 | 3.742 |
| 232.00 | 0.780 | 1.673 | 4.368 | 4.326 | 0.042 | 5.441 | 0.178 | 3.742 |
| 236.00 | 0.780 | 1.688 | 4.369 | 4.330 | 0.039 | 5.445 | 0.178 | 3.742 |
| 238.00 | 0.780 | 1.695 | 4.369 | 4.340 | 0.029 | 5.455 | 0.178 | 3.742 |
| 240.00 | 0.780 | 1.702 | 4.369 | 4.340 | 0.029 | 5.455 | 0.178 | 3.742 |
| 246.00 | 0.780 | 1.719 | 4.369 | 4.357 | 0.012 | 5.472 | 0.178 | 3.742 |
| 250.00 | 0.780 | 1.730 | 4.370 | 4.361 | 0.009 | 5.476 | 0.178 | 3.742 |
| 255.00 | 0.780 | 1.743 | 4.370 | 4.365 | 0.005 | 5.480 | 0.178 | 3.742 |
| 260.00 | 0.780 | 1.755 | 4.371 | 4.364 | 0.007 | 5.479 | 0.178 | 3.742 |
| 265.00 | 0.780 | 1.766 | 4.371 | 4.360 | 0.011 | 5.475 | 0.178 | 3.742 |
| 270.00 | 0.780 | 1.777 | 4.371 | 4.375 | -0.004 | 5.490 | 0.178 | 3.742 |
| 275.00 | 0.780 | 1.787 | 4.371 | 4.380 | -0.009 | 5.495 | 0.178 | 3.742 |

is the correction factor for earlier discharges

e equation for line of best fit is S = aQ + bH + cQ^2 + k

e values calculated for this equation are :

(a) (b) (c) (k)

Sw= -0.66200E-01 * Q + 0.29837E-01 * H + 0.61501E+01 * Q^2 + 0.62807E+00

suggested maximum drawdown 5.87m assumed to occur at log time 5.16 or 144000.0 time units

calculated long term pumping rate 0.916 m^3/min

calculated Transmissivity 0.61343E+01 m^3/min/m

STEP DRAWDOWN TEST N32/19 (HAZEL'S SOLUTION)

STEP DRAWDOWN PROGRAM VAX VERSION

TABLE OF VALUES

| Time | Discharge | H | Computed Drawdown | Actual Drawdown | Diff in Drawdown | Recorded Head | 24 Hr Q/S | Well Loss |
|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.115 | | |
| 0.50 | 0.420 | -0.126 | 1.631 | 1.687 | -0.056 | 2.802 | 0.249 | 0.81 |
| 1.00 | 0.420 | 0.000 | 1.636 | 1.687 | -0.051 | 2.802 | 0.249 | 0.81 |
| 1.50 | 0.420 | 0.074 | 1.639 | 1.688 | -0.049 | 2.803 | 0.249 | 0.81 |
| 2.00 | 0.420 | 0.126 | 1.641 | 1.695 | -0.054 | 2.810 | 0.249 | 0.81 |
| 3.00 | 0.420 | 0.200 | 1.644 | 1.697 | -0.053 | 2.812 | 0.249 | 0.81 |
| 4.00 | 0.420 | 0.253 | 1.647 | 1.704 | -0.057 | 2.819 | 0.249 | 0.81 |
| 5.00 | 0.420 | 0.294 | 1.648 | 1.706 | -0.058 | 2.821 | 0.249 | 0.81 |
| 6.00 | 0.420 | 0.327 | 1.649 | 1.707 | -0.058 | 2.822 | 0.249 | 0.81 |
| 7.00 | 0.420 | 0.355 | 1.651 | 1.707 | -0.056 | 2.822 | 0.249 | 0.81 |
| 8.00 | 0.420 | 0.379 | 1.652 | 1.710 | -0.058 | 2.825 | 0.249 | 0.81 |
| 9.00 | 0.420 | 0.401 | 1.652 | 1.712 | -0.060 | 2.827 | 0.249 | 0.81 |
| 10.00 | 0.420 | 0.420 | 1.653 | 1.708 | -0.055 | 2.823 | 0.249 | 0.81 |
| 12.00 | 0.420 | 0.453 | 1.654 | 1.706 | -0.052 | 2.821 | 0.249 | 0.81 |
| 14.00 | 0.420 | 0.481 | 1.656 | 1.705 | -0.049 | 2.820 | 0.249 | 0.81 |
| 16.00 | 0.420 | 0.506 | 1.657 | 1.707 | -0.050 | 2.822 | 0.249 | 0.81 |
| 18.00 | 0.420 | 0.527 | 1.657 | 1.703 | -0.046 | 2.818 | 0.249 | 0.81 |
| 20.00 | 0.420 | 0.546 | 1.658 | 1.702 | -0.044 | 2.817 | 0.249 | 0.81 |
| 25.00 | 0.420 | 0.587 | 1.660 | 1.720 | -0.060 | 2.835 | 0.249 | 0.81 |
| 30.00 | 0.420 | 0.620 | 1.661 | 1.715 | -0.054 | 2.830 | 0.249 | 0.81 |
| 35.00 | 0.420 | 0.649 | 1.662 | 1.717 | -0.055 | 2.832 | 0.249 | 0.81 |
| 40.00 | 0.420 | 0.673 | 1.663 | 1.715 | -0.052 | 2.830 | 0.249 | 0.81 |
| 45.00 | 0.420 | 0.694 | 1.664 | 1.716 | -0.052 | 2.831 | 0.249 | 0.81 |
| 50.00 | 0.420 | 0.714 | 1.665 | 1.718 | -0.053 | 2.833 | 0.249 | 0.81 |
| 55.00 | 0.420 | 0.731 | 1.666 | 1.716 | -0.050 | 2.831 | 0.249 | 0.81 |
| 56.50 | 0.500 | 0.750 | 2.145 | 2.128 | 0.017 | 3.243 | 0.230 | 1.15 |
| 57.00 | 0.500 | 0.762 | 2.145 | 2.130 | 0.015 | 3.245 | 0.230 | 1.15 |
| 57.50 | 0.500 | 0.771 | 2.146 | 2.134 | 0.012 | 3.249 | 0.230 | 1.15 |
| 58.00 | 0.500 | 0.779 | 2.146 | 2.133 | 0.013 | 3.248 | 0.230 | 1.15 |
| 59.00 | 0.500 | 0.792 | 2.147 | 2.138 | 0.009 | 3.253 | 0.230 | 1.15 |
| 60.00 | 0.500 | 0.803 | 2.147 | 2.139 | 0.008 | 3.254 | 0.230 | 1.15 |
| 61.00 | 0.500 | 0.812 | 2.147 | 2.140 | 0.007 | 3.255 | 0.230 | 1.15 |
| 62.00 | 0.500 | 0.820 | 2.148 | 2.143 | 0.005 | 3.258 | 0.230 | 1.15 |
| 63.00 | 0.500 | 0.828 | 2.148 | 2.145 | 0.003 | 3.260 | 0.230 | 1.15 |
| 64.00 | 0.500 | 0.835 | 2.148 | 2.145 | 0.003 | 3.260 | 0.230 | 1.15 |
| 65.00 | 0.500 | 0.841 | 2.148 | 2.145 | 0.003 | 3.260 | 0.230 | 1.15 |
| 67.00 | 0.500 | 0.853 | 2.149 | 2.146 | 0.003 | 3.261 | 0.230 | 1.15 |
| 69.00 | 0.500 | 0.864 | 2.149 | 2.145 | 0.004 | 3.260 | 0.230 | 1.15 |
| 71.00 | 0.500 | 0.874 | 2.150 | 2.145 | 0.005 | 3.260 | 0.230 | 1.15 |
| 73.00 | 0.500 | 0.883 | 2.150 | 2.145 | 0.005 | 3.260 | 0.230 | 1.15 |
| 75.00 | 0.500 | 0.892 | 2.150 | 2.144 | 0.006 | 3.259 | 0.230 | 1.15 |
| 80.00 | 0.500 | 0.911 | 2.151 | 2.161 | -0.010 | 3.276 | 0.230 | 1.15 |
| 85.00 | 0.500 | 0.929 | 2.152 | 2.160 | -0.008 | 3.275 | 0.230 | 1.15 |
| 90.00 | 0.500 | 0.944 | 2.153 | 2.160 | -0.007 | 3.275 | 0.230 | 1.15 |
| 95.00 | 0.500 | 0.959 | 2.153 | 2.160 | -0.007 | 3.275 | 0.230 | 1.15 |
| 100.00 | 0.500 | 0.972 | 2.154 | 2.161 | -0.007 | 3.276 | 0.230 | 1.15 |
| 105.00 | 0.500 | 0.985 | 2.154 | 2.161 | -0.007 | 3.276 | 0.230 | 1.15 |
| 110.00 | 0.500 | 0.997 | 2.155 | 2.161 | -0.006 | 3.276 | 0.230 | 1.15 |
| 113.00 | 0.618 | 1.060 | 2.971 | 2.922 | 0.049 | 4.037 | 0.206 | 1.76 |
| 114.00 | 0.618 | 1.077 | 2.971 | 2.928 | 0.043 | 4.043 | 0.206 | 1.76 |
| 115.00 | 0.618 | 1.090 | 2.972 | 2.938 | 0.034 | 4.053 | 0.206 | 1.76 |
| 116.00 | 0.618 | 1.102 | 2.972 | 2.945 | 0.027 | 4.060 | 0.206 | 1.76 |
| 117.00 | 0.618 | 1.112 | 2.973 | 2.945 | 0.028 | 4.060 | 0.206 | 1.76 |
| 118.00 | 0.618 | 1.121 | 2.973 | 2.946 | 0.027 | 4.061 | 0.206 | 1.76 |
| 119.00 | 0.618 | 1.129 | 2.973 | 2.949 | 0.024 | 4.064 | 0.206 | 1.76 |
| 120.00 | 0.618 | 1.136 | 2.974 | 2.952 | 0.022 | 4.067 | 0.206 | 1.76 |
| 122.00 | 0.618 | 1.150 | 2.974 | 2.954 | 0.020 | 4.069 | 0.206 | 1.76 |
| 124.00 | 0.618 | 1.162 | 2.975 | 2.953 | 0.022 | 4.068 | 0.206 | 1.76 |
| 126.00 | 0.618 | 1.172 | 2.975 | 2.960 | 0.015 | 4.075 | 0.206 | 1.76 |
| 128.00 | 0.618 | 1.182 | 2.975 | 2.961 | 0.014 | 4.076 | 0.206 | 1.76 |
| 130.00 | 0.618 | 1.191 | 2.976 | 2.962 | 0.014 | 4.077 | 0.206 | 1.76 |
| 135.00 | 0.618 | 1.212 | 2.977 | 2.970 | 0.007 | 4.085 | 0.206 | 1.76 |
| 140.00 | 0.618 | 1.230 | 2.977 | 2.970 | 0.007 | 4.085 | 0.206 | 1.76 |
| 145.00 | 0.618 | 1.246 | 2.978 | 2.972 | 0.006 | 4.087 | 0.206 | 1.76 |
| 150.00 | 0.618 | 1.261 | 2.979 | 2.974 | 0.005 | 4.089 | 0.206 | 1.76 |
| 155.00 | 0.618 | 1.275 | 2.979 | 2.976 | 0.003 | 4.091 | 0.206 | 1.76 |
| 160.00 | 0.618 | 1.288 | 2.980 | 2.980 | 0.000 | 4.095 | 0.206 | 1.76 |
| 165.00 | 0.618 | 1.300 | 2.980 | 2.979 | 0.001 | 4.094 | 0.206 | 1.76 |
| 170.00 | 0.723 | 1.385 | 3.815 | 3.855 | -0.040 | 4.970 | 0.188 | 2.40 |
| 171.00 | 0.723 | 1.395 | 3.815 | 3.869 | -0.054 | 4.984 | 0.188 | 2.40 |
| 172.00 | 0.723 | 1.405 | 3.816 | 3.868 | -0.052 | 4.983 | 0.188 | 2.40 |
| 173.00 | 0.723 | 1.413 | 3.816 | 3.875 | -0.059 | 4.990 | 0.188 | 2.40 |
| 174.00 | 0.723 | 1.420 | 3.816 | 3.876 | -0.060 | 4.991 | 0.188 | 2.40 |
| 175.00 | 0.723 | 1.427 | 3.817 | 3.880 | -0.063 | 4.995 | 0.188 | 2.40 |
| 177.00 | 0.723 | 1.440 | 3.817 | 3.885 | -0.068 | 5.000 | 0.188 | 2.40 |
| 179.00 | 0.723 | 1.451 | 3.818 | 3.885 | -0.067 | 5.000 | 0.188 | 2.40 |
| 181.00 | 0.723 | 1.461 | 3.818 | 3.888 | -0.070 | 5.003 | 0.188 | 2.40 |
| 181.00 | 0.723 | 1.461 | 3.818 | 3.888 | -0.070 | 5.003 | 0.188 | 2.40 |
| 183.00 | 0.723 | 1.470 | 3.818 | 3.891 | -0.073 | 5.006 | 0.188 | 2.40 |
| 185.00 | 0.723 | 1.479 | 3.819 | 3.895 | -0.076 | 5.010 | 0.188 | 2.40 |
| 190.00 | 0.723 | 1.499 | 3.819 | 3.897 | -0.078 | 5.012 | 0.188 | 2.40 |
| 195.00 | 0.723 | 1.516 | 3.820 | 3.897 | -0.077 | 5.012 | 0.188 | 2.40 |
| 200.00 | 0.723 | 1.532 | 3.821 | 3.898 | -0.077 | 5.013 | 0.188 | 2.40 |
| 205.00 | 0.723 | 1.547 | 3.821 | 3.900 | -0.079 | 5.015 | 0.188 | 2.40 |
| 210.00 | 0.723 | 1.568 | 3.822 | 3.905 | -0.083 | 5.020 | 0.188 | 2.40 |
| 215.00 | 0.723 | 1.578 | 3.823 | 3.909 | -0.086 | 5.024 | 0.188 | 2.40 |
| 220.00 | 0.723 | 1.585 | 3.823 | 3.911 | -0.088 | 5.026 | 0.188 | 2.40 |
| 222.50 | 0.780 | 1.624 | 4.318 | 4.312 | 0.006 | 5.427 | 0.179 | 2.80 |
| 224.00 | 0.780 | 1.628 | 4.318 | 4.310 | 0.008 | 5.425 | 0.179 | 2.80 |
| 225.00 | 0.780 | 1.636 | 4.319 | 4.324 | -0.005 | 5.439 | 0.179 | 2.80 |
| 226.00 | 0.780 | 1.643 | 4.319 | 4.325 | -0.006 | 5.440 | 0.179 | 2.80 |
| 227.00 | 0.780 | 1.649 | 4.319 | 4.323 | -0.004 | 5.438 | 0.179 | 2.80 |
| 228.00 | 0.780 | 1.654 | 4.319 | 4.326 | -0.007 | 5.441 | 0.179 | 2.80 |
| 229.00 | 0.780 | 1.659 | 4.320 | 4.326 | -0.006 | 5.441 | 0.179 | 2.80 |
| 230.00 | 0.780 | 1.664 | 4.320 | 4.328 | -0.008 | 5.443 | 0.179 | 2.80 |
| 232.00 | 0.780 | 1.673 | 4.320 | 4.326 | -0.006 | 5.441 | 0.179 | 2.80 |
| 236.00 | 0.780 | 1.688 | 4.321 | 4.330 | -0.009 | 5.445 | 0.179 | 2.80 |
| 238.00 | 0.780 | 1.695 | 4.321 | 4.340 | -0.019 | 5.455 | 0.179 | 2.80 |
| 240.00 | 0.780 | 1.702 | 4.321 | 4.340 | -0.019 | 5.455 | 0.179 | 2.80 |
| 245.00 | 0.780 | 1.719 | 4.322 | 4.357 | -0.035 | 5.472 | 0.179 | 2.80 |
| 250.00 | 0.780 | 1.730 | 4.323 | 4.361 | -0.038 | 5.476 | 0.179 | 2.80 |
| 255.00 | 0.780 | 1.743 | 4.323 | 4.365 | -0.042 | 5.480 | 0.179 | 2.80 |
| 260.00 | 0.780 | 1.755 | 4.323 | 4.364 | -0.041 | 5.479 | 0.179 | 2.80 |
| 265.00 | 0.780 | 1.766 | 4.324 | 4.360 | -0.036 | 5.475 | 0.179 | 2.80 |
| 270.00 | 0.780 | 1.777 | 4.324 | 4.375 | -0.051 | 5.490 | 0.179 | 2.80 |
| 275.00 | 0.780 | 1.787 | 4.325 | 4.380 | -0.055 | 5.495 | 0.179 | 2.80 |

H is the correction factor for earlier discharges

The equation for line of best fit is S = aQ + bH + cQ^2 + k

The values calculated for this equation are :-

(a) (b) (c) (k)

S = 0.17500E+01 * Q + 0.39800E-01 * H + 0.46000E+01 * Q^2 + 0.90000E-01

Suggested maximum drawdown 5.87m assumed to occur at log time 5.16 or 144000.0 time units

Calculated long term pumping rate 0.926 m^3/min/m

Calculated Transmissivity 0.45987E+01 m^3/min/m

APPENDIX 4.9 – Data and drawdown curves obtained from constant discharge pump test carried out on bore 033-74, Mina.

OBSERVATIONS DURING PUMPING/RECOVERY

Location Cheviot Three Pumping Test

Well 033/50 M. Lawler  Distance 24.7 from pumped well

Start 10.11 am  Stop Obs Well 2 Drawdown.

Initial water level 0.899  Final water level

Reference level  =  m above M.S.L.

Q = 109.1 $m^3$/day.

| Time min. | Water Level m | Rise/ Fall | Time min. | Water Level m | Rise / Fall |
|---|---|---|---|---|---|
| 0 | 0.899 | 0.000 | 70 | 1.155 | 0.256 |
| ½ | 0.899 | 0.000 | 80 | 1.189 | 0.290 |
| 1 | 0.899 | 0.000 | 90 | 1.229 | 0.330 |
| 1½ | 0.899 | 0.000 | 100 | 1.253 | 0.354 |
| 2 | 0.899 | 0.000 | 120 | 1.284 | 0.385 |
| 2½ | 0.899 | 0.000 | 150 | 1.328 | 0.429 |
| 3 | 0.899 | 0.000 | 180 | 1.365 | 0.466 |
| 3½ | 0.899 | 0.000 | 210 | 1.390 | 0.491 |
| 4 | 0.899 | 0.000 | 240 | 1.430 | 0.531 |
| 4½ | 0.900 | 0.001 | | | |
| 5 | 0.900 | 0.001 | | | |
| 6 | 0.900 | 0.001 | | | |
| 7 | 0.900 | 0.001 | | | |
| 8 | 0.900 | 0.001 | | | |
| 9 | 0.902 | 0.003 | | | |
| 10 | 0.903 | 0.004 | | | |
| 12 | 0.906 | 0.007 | | | |
| 14 | 0.910 | 0.011 | | | |
| 16 | 0.914 | 0.015 | | | |
| 18 | 0.918 | 0.019 | | | |
| 20 | 0.924 | 0.025 | | | |
| 25 | 0.944 | 0.045 | | | |
| 30 | 0.973 | 0.074 | | | |
| 35 | 0.998 | 0.099 | | | |
| 40 | 1.020 | 0.121 | | | |
| 45 | 1.051 | 0.152 | | | |
| 50 | 1.076 | 0.177 | | | |
| 55 | | | | | |
| 60 | 1.115 | 0.216 | | | |

OBSERVATIONS DURING PUMPING/RECOVERY

Location Cheviot Three Pump Test

Well 033/50  Distance 24.7

Start  Stop Obs 2 Recovery

Initial water level $s_i$ 0.899  Final water level

Reference level  =  m above M.S.L.

| TOTAL TIME t | STEP TIME t' | RATIO t/t' | RESIDUAL DRAWDOWN $s_{t'}-s_i$ | | WATER LEVEL s at t' m |
|---|---|---|---|---|---|
| 240 | 0 | ∞ | 0.531 | | 1.430 |
| 240.5 | ½ | 481 | 0.531 | | 1.430 |
| 241 | 1 | 241 | 0.531 | | 1.430 |
| 241.5 | 1½ | 161 | 0.531 | | 1.430 |
| 242 | 2 | 121 | 0.531 | | 1.430 |
| 242.5 | 2½ | 97 | 0.532 | | 1.429 |
| 243 | 3 | 81 | 0.534 | | 1.427 |
| 24 | 3½ | 70 | 0.534 | | 1.427 |
| 244 | 4 | 61 | 0.534 | | 1.427 |
| 244.5 | 4½ | 54 | | | |
| 245 | 5 | 49 | 0.538 | | 1.423 |
| 246 | 6 | 41 | 0.512 | | 1.411 |
| 247 | 7 | 35 | 0.496 | | 1.395 |
| 248 | 8 | 31 | 0.476 | | 1.375 |
| 249 | 9 | 28 | 0.455 | | 1.354 |
| 250 | 10 | 25 | 0.436 | | 1.335 |
| 252 | 12 | 21 | 0.401 | | 1.300 |
| 254 | 14 | 18 | 0.376 | | 1.275 |
| 256 | 16 | 16 | 0.350 | | 1.249 |
| 258 | 18 | 14 | 0.325 | | 1.224 |
| 260 | 20 | 13 | 0.306 | | 1.205 |
| 265 | 25 | 11 | 0.270 | | 1.169 |
| 270 | 30 | 9 | 0.245 | | 1.144 |
| 275 | 35 | 8 | 0.216 | | 1.115 |
| 280 | 40 | 7 | 0.196 | | 1.095 |
| 285 | 45 | 6.3 | 0.178 | | 1.077 |
| 290 | 50 | 5.8 | 0.162 | | 1.061 |
| 295 | 55 | 5.3 | 0.151 | | 1.050 |
| 300 | 60 | 5.0 | 0.137 | | 1.036 |
| 310 | 70 | 4.4 | 0.118 | | 1.017 |
| 330 | 90 | 3.7 | 0.094 | | 0.993 |

OBSERVATIONS DURING PUMPING/RECOVERY

Location: Cheviot Three Pumping Test

Well: 033/75 J Purdie

Distance: 11·90 m from pumped well

Start: 10·11 am

Stop: Obs Well 1 Drawdown

Initial water level: 0·312

Final water level:

Reference level: = m above M.S.L.

| Time min. | Water Level m | Rise/ Fall | Time min. | Water Level m | Rise / Fall |
|---|---|---|---|---|---|
| 0 | 0·312 | 0·000 | 70 | 1·180 | 0·868 |
| ½ | 0·483 | 0·171 | 80 | 1·200 | 0·888 |
| 1 | 0·592 | 0·280 | 90 | 1·220 | 0·908 |
| 1½ | 0·642 | 0·330 | 100 | 1·233 | 0·921 |
| 2 | 0·682 | 0·370 | 120 | 1·263 | 0·951 |
| 2½ | 0·708 | 0·396 | 150 | 1·290 | 0·978 |
| 3 | 0·736 | 0·424 | 180 | 1·311 | 0·999 |
| 3½ | 0·755 | 0·443 | 210 | 1·336 | 1·024 |
| 4 | 0·776 | 0·464 | 240 | 1·352 | 1·040 |
| 4½ | 0·790 | 0·478 | | | |
| 5 | 0·814 | 0·502 | | | |
| 6 | 0·836 | 0·524 | | | |
| 7 | 0·858 | 0·546 | | | |
| 8 | 0·873 | 0·561 | | | |
| 9 | 0·906 | 0·594 | | | |
| 10 | 0·916 | 0·604 | | | |
| 12 | 0·930 | 0·618 | | | |
| 14 | 0·951 | 0·639 | | | |
| 16 | 0·971 | 0·659 | | | |
| 18 | 0·986 | 0·674 | | | |
| 20 | 1·004 | 0·692 | | | |
| 25 | 1·039 | 0·727 | | | |
| 30 | 1·063 | 0·751 | | | |
| 35 | 1·081 | 0·769 | | | |
| 40 | 1·105 | 0·793 | | | |
| 45 | 1·121 | 0·809 | | | |
| 50 | 1·132 | 0·820 | | | |
| 55 | 1·151 | 0·839 | | | |
| 60 | 1·167 | 0·855 | | | |

Q = 109·1 $m^3$/day

OBSERVATIONS DURING PUMPING/RECOVERY

Location: Cheviot Three Pump Test

Well: 033/75 J Purdie

Distance: 11·90 m

Start: 14·13 hrs

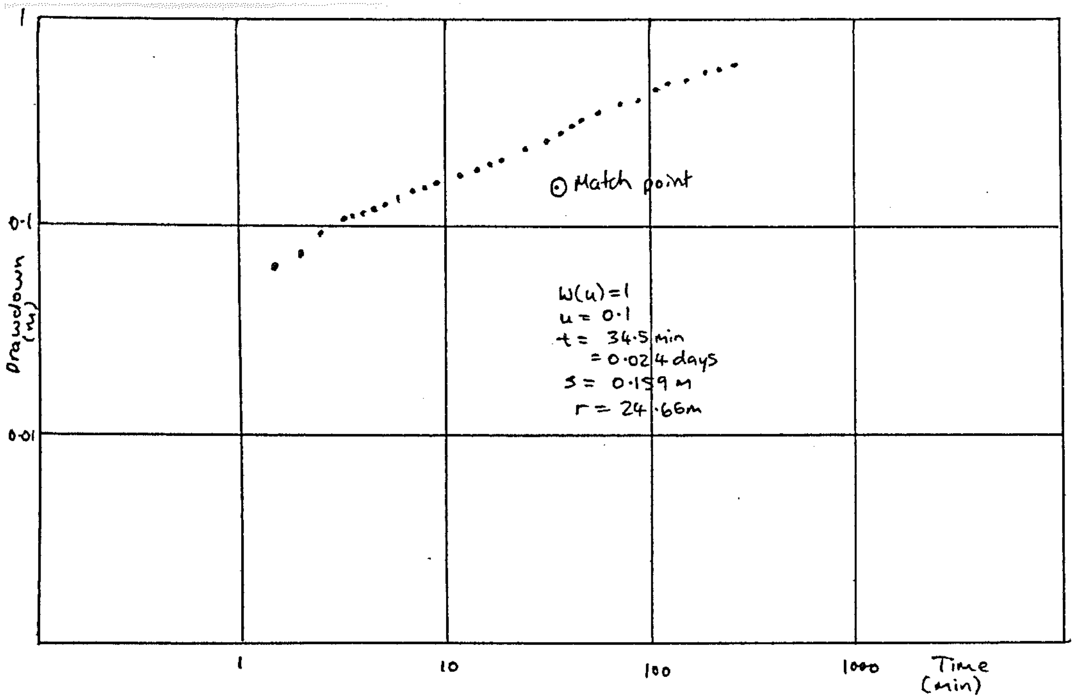
Stop: Obs 1 Recovery

Initial water level $s_i$: 0·312 m

Final water level:

Reference level: = m above M.S.L.

| TOTAL TIME t | STEP TIME t' | RATIO t/t' | RESIDUAL DRAWDOWN $s_{t'}-s_i$ | | WATER LEVEL s at t' m |
|---|---|---|---|---|---|
| 240 | 0 | ∞ | | | 1·349 |
| 240·5 | ½ | 481 | 0·858 | | 1·170 |
| 241 | 1 | 241 | 0·754 | | 1·066 |
| 241·5 | 1½ | 161 | 0·708 | | 1·020 |
| 242 | 2 | 121 | 0·657 | | 0·969 |
| 242·5 | 2½ | 97 | 0·622 | | 0·934 |
| 243 | 3 | 81 | 0·599 | | 0·911 |
| 243·5 | 3½ | 70 | 0·572 | | 0·884 |
| 244 | 4 | 61 | 0·553 | | 0·865 |
| 244·5 | 4½ | 54 | 0·539 | | 0·851 |
| 245 | 5 | 49 | 0·527 | | 0·839 |
| 246 | 6 | 41 | 0·498 | | 0·810 |
| 247 | 7 | 35 | 0·471 | | 0·783 |
| 248 | 8 | 31 | 0·444 | | 0·756 |
| 249 | 9 | 28 | 0·427 | | 0·739 |
| 250 | 10 | 25 | 0·412 | | 0·724 |
| 252 | 12 | 21 | 0·388 | | 0·700 |
| 254 | 14 | 18 | 0·361 | | 0·673 |
| 256 | 16 | 16 | 0·337 | | 0·649 |
| 258 | 18 | 14 | 0·318 | | 0·630 |
| 260 | 20 | 13 | 0·308 | | 0·620 |
| 265 | 25 | 11 | 0·269 | | 0·581 |
| 270 | 30 | 9 | 0·238 | | 0·550 |
| 275 | 35 | 8 | 0·219 | | 0·531 |
| 280 | 40 | 7 | 0·202 | | 0·514 |
| 285 | 45 | 6·3 | 0·187 | | 0·499 |
| 290 | 50 | 5·8 | 0·175 | | 0·487 |
| 295 | 55 | 5·3 | 0·162 | | 0·474 |
| 300 | 60 | 5·0 | 0·152 | | 0·464 |
| 310 | 70 | 4·4 | 0·135 | | 0·447 |
| 320 | 80 | 4·0 | 0·102 | | 0·414 |




OBS bore # 2

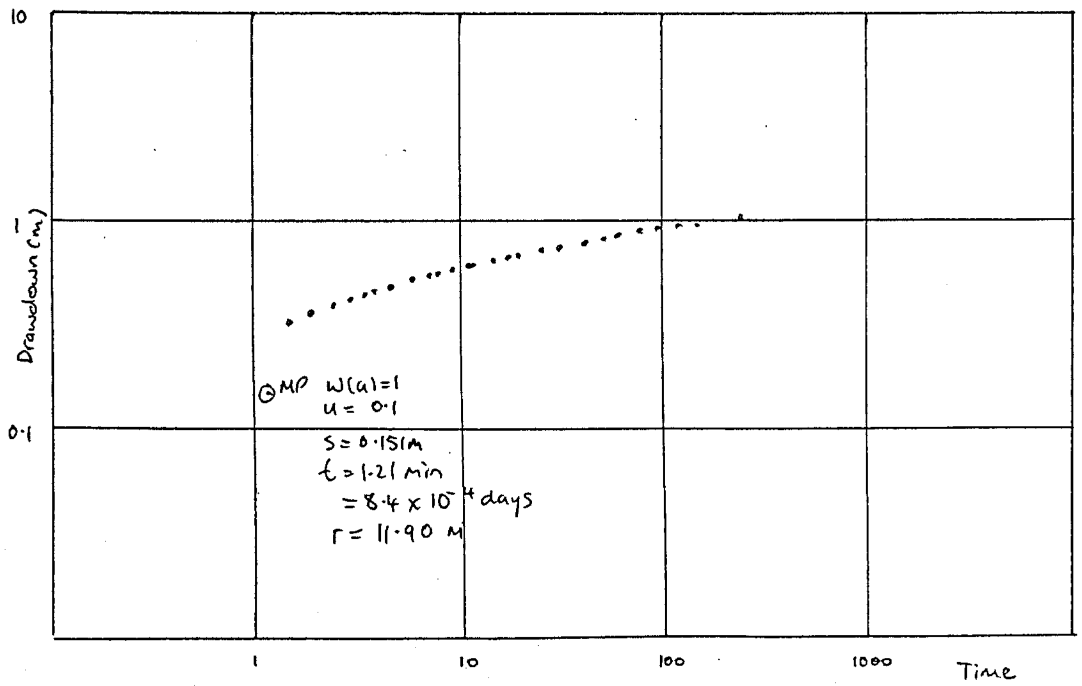
$Q = 109.1\ m^3/day$

$$T = \frac{Q}{4\pi} \times \frac{W(u)}{s} \qquad S = \frac{4 \times T \times u \times t}{r^2}$$

$$T = \frac{109.1}{4\pi} \cdot \frac{1}{0.159} \qquad S = \frac{4\,(54.6)\,(0.1)\,(0.00239)}{24.6}$$

$$T = 54.6\ m^2/day \qquad S = 2.12 \times 10^{-3}$$

Thus Transmissivity $= 54.6\ m^2/day$ and Storativity $= 8.59 \times 10^{-}$




OBS bore # 1

$Q = 109.1\ m^3/day$

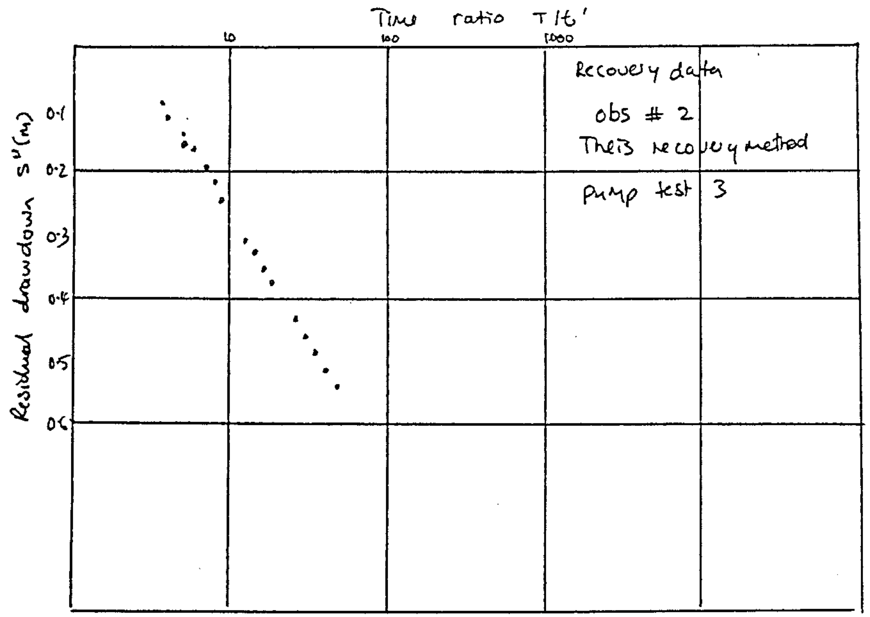
$$T = \frac{Q}{4\pi s} \times W(u) \qquad S = \frac{4 \times T \times u \times t}{r^2}$$

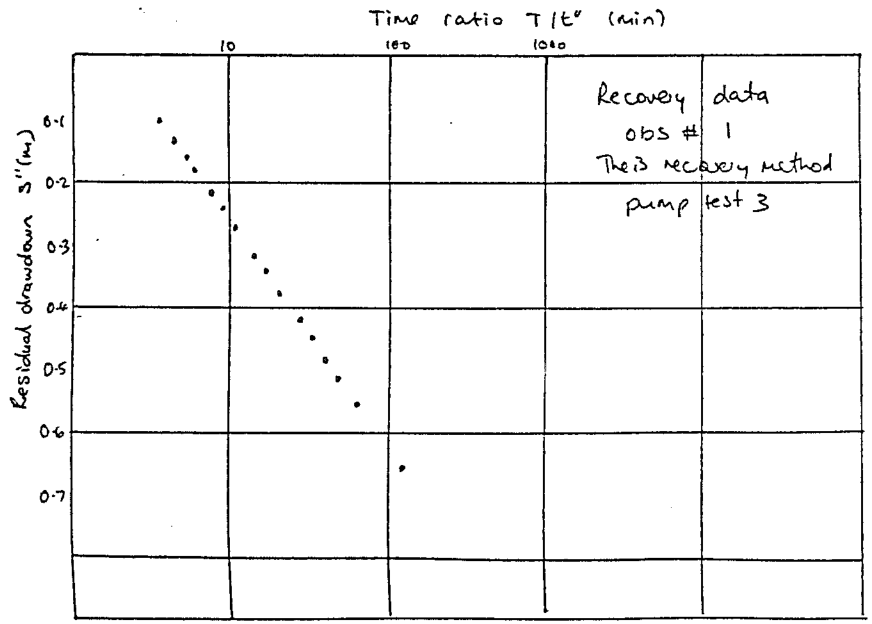
$$T = \frac{109.1\ (1)}{4\pi\ (0.51)} \qquad S = \frac{4\ (59.5)(0.1)(8.403 \times 10^{-4})}{(11.9)^2}$$

$$T = 57.5\ m^2/day \qquad S = 1.365 \times 10^{-4}$$

Thus Transmissivity $= 57.5\ m^2/day$

and Storativity $= 1.32 \times 10^{-4}$




obs # 2

$$T = \frac{2.3 \times Q}{4\pi \times s''}$$

$$T = \frac{2.3 \times 109.1}{4 \times \pi \times 0.40}$$

$$T = \frac{250.9}{5.0} = 50.2 \ m^2/day$$

obs # 1

$$T = \frac{2.3 \times Q}{4\pi \times \Delta s''}$$

$$T = \frac{2.3 \times 109.1}{4\pi \times 0.40}$$

$$T = \frac{250.9}{5.0} = 50.2 \ m^2/day.$$